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The Geological History
of the
Connecticut Valley

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The Geological History
of the
Connecticut Valley of Massachusetts

A Popular Account of its Rocks and Origin

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PREFACE

The purpose of this little book is to present, in popular form, the salient points in the geological history of the Connecticut Valley of Massachusetts. The beautiful valley and its charming boundary hills may in truth be said to be a geologist's paradise. In regard to variety of geological phenomena, few districts of equal size in North America surpass it. To most of its residents the marvelous story of the Connecticut Valley and adjacent hills as recorded in nature's book of the rocks is unknown. Beginning with the oldest decipherable records and leading up to the present time, it is my pleasure, in the following pages, to explain to the layman the principal known events in the wonderful geological history of the Connecticut Valley, including the origin of the valley as we see it today.

The use of technical and unusual terms has been reduced to a minimum compatible with a reasonable understanding of the subject. Each of the few technical terms is explained where first used in the text.

Since so many of the great principles of earth science (geology) are wonderfully illustrated in the Connecticut Valley and the adjacent highlands, it is my hope that this book may furnish the basis and inspiration to many people of the region for understanding and interpreting not only the principal records of the rocks, but also the important processes and laws of the science of geology illustrated by these records. To aid in the accomplishment of this purpose, simplified, largely nontechnical, scientific discussions are entered into. In order to make the conclusions more impressive and realistic actual easily accessible localities, carefully selected out of my field experience, are cited to illustrate each stage in the tremendously long history of the region. I am not satisfied to say to the reader, for example, "long ages ago, according to geologists, the sea spread over central western Massachusetts". My purpose is to be much more precise than that, and to give the reader at least some of the geological reasoning upon which such conclusions are based.

This little book might well be dedicated to two distinguished geologists—Edward Hitchcock, who was many years ago, Professor in, and then President of, Amherst College, and Benjamin K. Emerson who, for many years after Hitchcock's time, was Professor of Geology in Amherst College, and is now Professor Emeritus. To these two men, whose keen minds and indefatigable labors have made the

Connecticut Valley famous among the geologists of the world, I hereby acknowledge my indebtedness. Professor Emerson's writings have been freely drawn upon, especially his Holyoke Folio (No. 50), Geology of Old Hampshire County (Monograph 29), and The Geology of Massachusetts and Rhode Island (Bulletin 597), all published by the United States Geological Survey.

During my residence in the Connecticut Valley both the beauty of the landscape and the great variety of rock formations ranging in age back to remote geologic time have been constant sources of inspiration to me. Throughout western Massachusetts I have made many geological observations which have been constantly in mind during the selection and presentation of the salient points in the history of the region.

With a few exceptions, where proper credit is given, I have made all the drawings and taken all the pictures which illustrate the text.

W. J. MILLER,

Smith College, May, 1921.

GEOGRAPHY OF CENTRAL WESTERN MASSACHUSETTS

The three counties of Franklin, Hampshire, and Hampden cover central western Massachusetts, the geological history of which is the subject of this book. These counties are only a little smaller than the whole drainage basin of the Connecticut River within the state. In the broad sense of the term this drainage basin constitutes the Connecticut Valley, or more precisely the Connecticut Valley System because it includes the more restricted Connecticut Valley proper and many tributary valleys. The broader valley or drainage basin, which is 50 to 60 miles wide, is bounded on the west by the Berkshire Hills and on the east by the Worcester County plateau of the central part of the state. The Connecticut Valley proper, or inner valley of the great drainage basin, is in general a great lowland which trends north and south for 48 miles across the state through the midst of Franklin, Hampshire, and Hampden Counties, (see figure 1). Hereafter, in order to avoid confusion in the use of terms, we shall refer to this lowland as the "Connecticut Valley" and that portion of the broader drainage area as comprised within the three counties as "central western Massachusetts".

The Connecticut Valley proper is a great lowland (see figure 1) whose broad floor varies from less than 100 feet to only a few hundred feet above sea level. Within these limits there is, however, considerable diversity of relief or topography. From Northampton northward the valley floor, which is mostly very flat, is from 5 to 10 miles wide, and from Northampton southward it is 15 to 20 miles wide.

Several bold hills or small mountains rise above the floor of the valley adding a touch of real grandeur to the landscape. Without doubt the most picturesque part of the entire Connecticut Valley is in the general vicinity of Northampton. Perhaps most impressive of all is the Mount Tom Range several miles long rising boldly many hundreds of feet above the general level of the valley (see figure 2). The climax is reached at Mount Tom whose summit lies 1214 feet above the sea and 1000 or more feet above the valley floor on the east and west sides. Each year from the top of this sentinel of the valley many people enjoy the view of the picturesque landscape. Mount Nonotuck at the north end of the range shows an altitude of 852 feet.

From Mount Tom southward a much lower though very distinct ridge rises above the valley floor all the way into Connecticut.



FIG. 1. RELIEF MAP OF CENTRAL WESTERN MASSACHUSETTS SHOWING THE PRINCIPAL TOPOGRAPHIC FEATURES. PHOTOGRAPHED BY THE AUTHOR

Beginning just east of the river from the Mount Tom Range, and extending eastward for 6 or 8 miles, is the Mount Holyoke Range which is nearly as impressive in height and boldness of relief as the Mount Tom Range, (see figure 3). The summit of Mount Holyoke shows an altitude of 954 feet, and that of Mount Norwottock, several miles farther east, 1115 feet.

Mount Warner (altitude 500 feet) forms a conspicuous feature of the valley landscape between Hatfield and Amherst.

East of Sunderland the steep faced mountain ridge called Mount Toby rises boldly 1000 feet or more above the valley lowland. Viewed from the west or southwest it shows a strikingly even "sky-line", the highest point of which lies 1275 feet above sea level. It is separated from the great eastern highland region by a deep narrow valley.

Between Sunderland and South Deerfield there are two high steep hills known as North Sugarloaf and South Sugarloaf. As viewed from the south for distances up to 10 miles South Sugarloaf stands out very conspicuously above the valley floor as a rock tower fully 500 feet high (see figure 4). Near views from the east and west show the high cliffs of red rock of which the hill is made. Its altitude is 709 feet. Of its kind it is probably the most unique landscape feature of the state.

Beginning just north of North Sugarloaf the Deerfield Range or ridge extends northward as a prominent ridge usually some hundreds of feet high. Its highest portion (altitude 822 feet) is southeast of Deerfield village.

The principal cities of central western Massachusetts are situated on the Connecticut Valley lowland. From south to north these are as follows with their populations: Springfield (130,000); Westfield (19,000); Chicopee (36,000); Holyoke (60,000); Northampton (22,000); and Greenfield (15,000).

The lowland of the Connecticut Valley is bounded on either side by a great upland or highland region. Steep hillsides or even mountain sides of the highlands nearly everywhere face the lowland of the valley. The picture of the relief map model (figure 1) gives a good idea of these topographic relations. As viewed from the valley floor, but still better from the top of Mount Tom, each upland presents a remarkably even sky-line with no peaks rising notably above the general level. The effect is to make each upland look like a long high nearly level ridge. From some good outlook point, like Chesterfield, in the midst of the western highland the observer

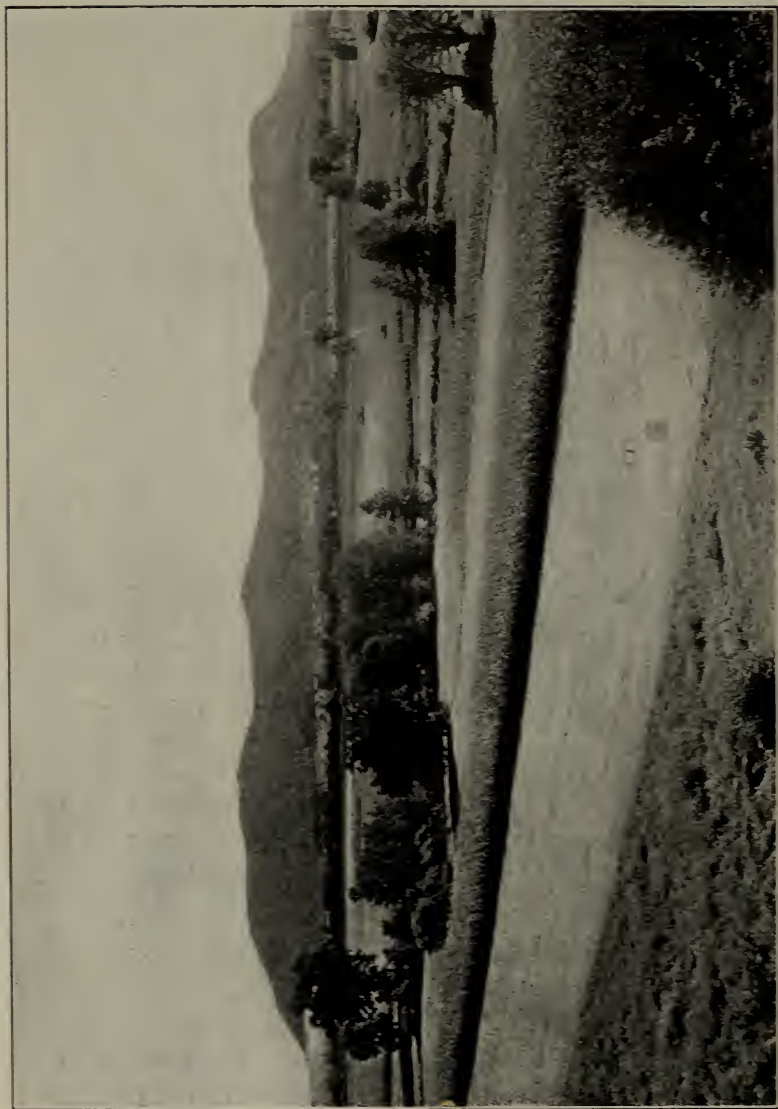


FIG. 2. THE MOUNT TOM RANGE AS SEEN FROM NORTHAMPTON ACROSS THE LEVEL FLOOR OF PART OF THE CONNECTICUT VALLEY
BY CHAS. H. HOWARD. PHOTOGRAPHER, NORTHAMPTON

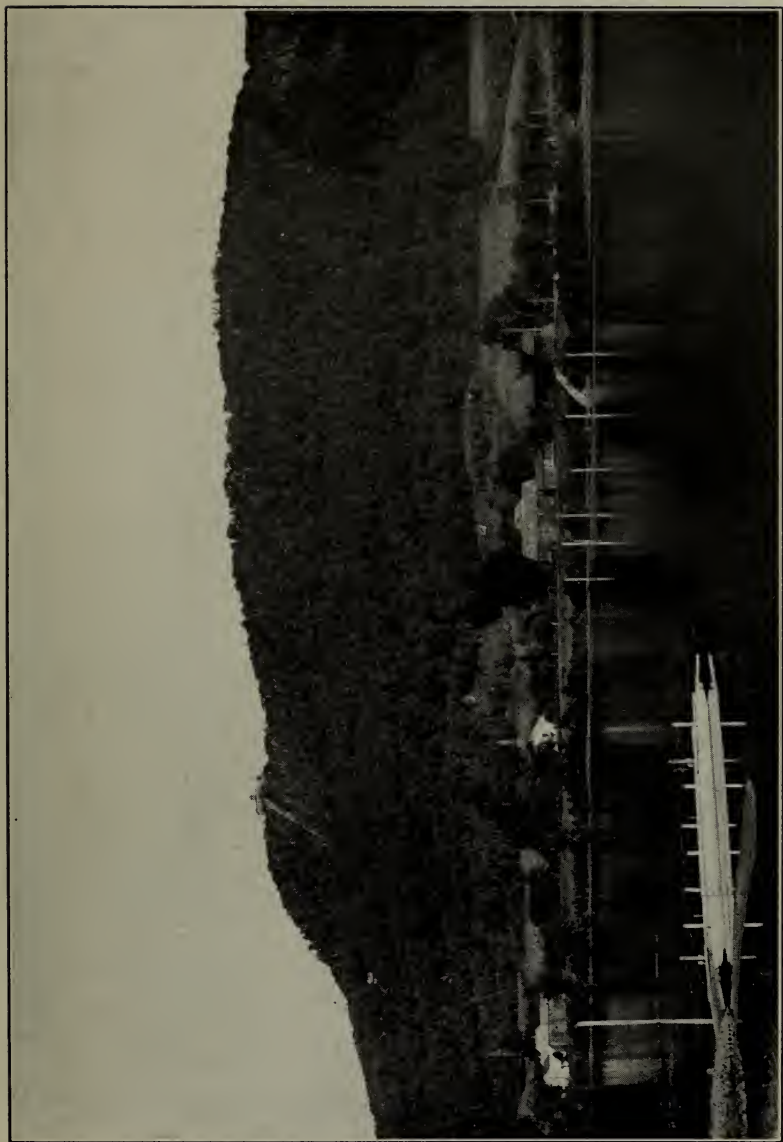


FIG. 3. MOUNT HOLYOKE FROM THE WEST BANK OF THE CONNECTICUT RIVER AT THE OLD HOCKANUM FERRY
BY CHAS. H. HOWARD, PHOTOGRAPHER, NORTHAMPTON

is impressed with the evenness of the sky-line in all directions. Chesterfield village itself lies about 1500 feet above sea level, and this is approximately the altitude of most of the higher points of the landscape for miles around. Very soon the observer notices that the upland is not a relatively smooth plateau surface but rather a maze of hills and valleys. Most of the very hilly western plateau is drained by two large tributaries of the Connecticut—Westfield River and Deerfield River. A perfect network of swift streams tributary to these two rivers drains practically the whole western upland except parts of the eastern side where some streams take direct courses into the Connecticut.

The great eastern upland is also a very hilly plateau in all important respects like the western upland except that it is in general a few hundred feet lower. Excellent views may be obtained from Pelham and Shutesbury which are at high altitudes (1100 to 1200 feet) on the plateau. Most of the drainage of the eastern upland passes into the Connecticut through two of its large tributaries—Millers River and Chicopee River.

THE MEANING OF GEOLOGY

The person of ordinary intelligence surrounded as he is by a great variety of physical features is, unless he has devoted some study to the subject, very likely to regard those features as practically unchangeable, and to think that they are now essentially as they were in the beginning of the earth's history. But the geologist knows beyond the shadow of a doubt that the face of the earth, as we behold it today, represents merely a single phase of a very long continued history. Great and revolutionary changes in the physical features of central western Massachusetts took place millions of years before the beautiful Connecticut Valley of the present time came into existence.

Geology, meaning literally "earth science", deals with the history of the earth and its inhabitants as revealed in the rocks. The science is very broad in its scope. It treats of the processes by which the earth has been, and is now being, changed; the materials and structure of the earth; the stages through which it has passed; and the evolution of the organisms which have lived upon it.

The following statements of some of the more definite important conclusions regarding earth changes may serve to make still clearer the general scope and significance of geology. Many of the evidences

upon which these conclusions are based are discussed in various parts of this book. For untold millions of years the rocks at and near the surface of the earth have been crumbling; streams have been incessantly sawing into the lands; the sea has been eating into continental masses; the winds have been sculpturing desert lands; and more intermittently and locally glaciers have plowed through mountain valleys, and even great sheets of ice have spread over considerable portions of continents. Throughout geologic time the crust of the earth has shown marked instability. Slow upward and downward movements of the lands relative to sea level have been very common, in many cases amounting to even thousands of feet. Various parts of the earth have been, and are being, affected by sudden movements (resulting in earthquakes) along fractures in the outer crust. During the millions of years, molten rocks have, at various times, been forced into the earth's crust and in many cases to its surface. Mountain ranges have been brought forth and cut down. The site of the Berkshire hills was, millions of years ago, the bottom of a shallow sea. Over certain parts of the continent, as for example western Massachusetts, the sea has advanced and retreated repeatedly. Lakes have come and gone. Organisms have inhabited the earth for many millions of years. In earlier known geologic time the plants and animals were comparatively simple and low in the scale of organization. Through the succeeding ages higher and more complex types were gradually evolved until the highly organized forms of the present time, including the human race, were produced.

“There rolls the deep where grew the tree.
O, earth, what changes thou hast seen!
There where the long street roars, hath been
The stillness of the central sea.

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.”

TENNYSON.

In the study of the many changes which have taken place during the history of the earth, a fundamental consideration is the determination of the relative ages of the rocks, especially the strata. How can the geologist assign a rock formation to a particular age

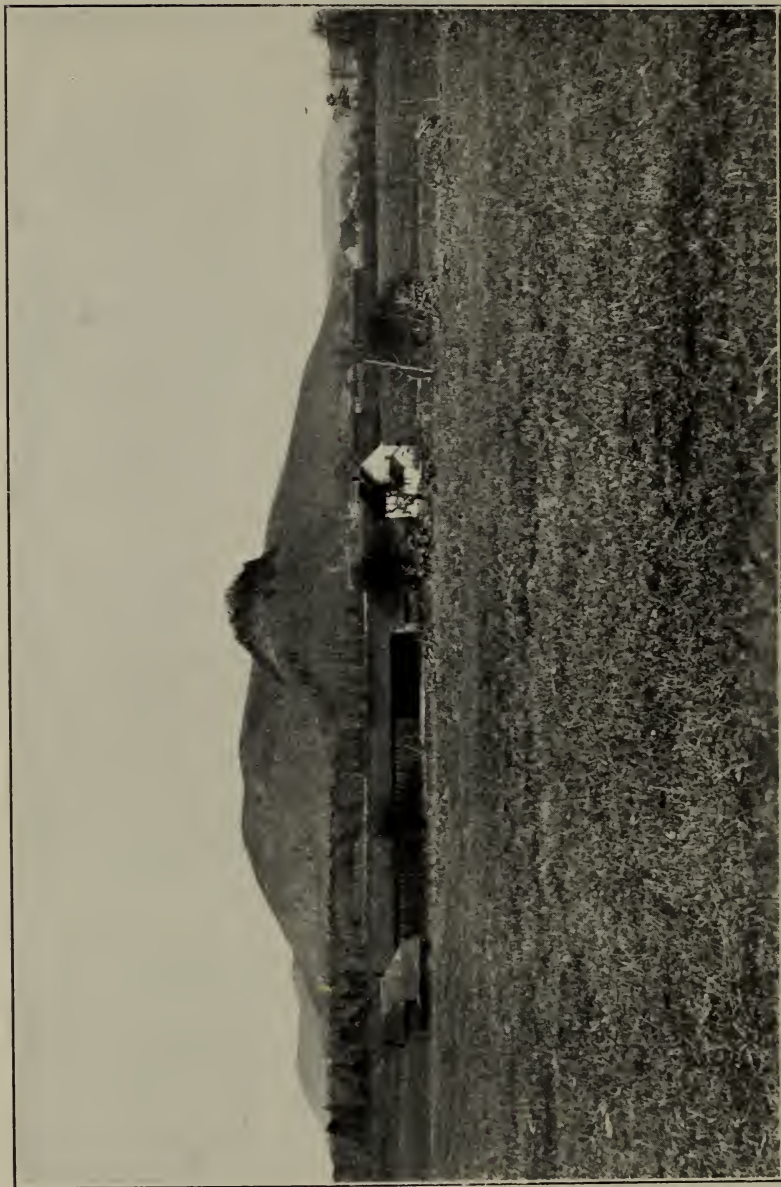


FIG. 4. SOUTH AND NORTH SUGARLOAF MOUNTAINS FROM A POINT ONE MILE EAST OF WHATELY STATION. PHOTOGRAPHED BY THE AUTHOR

in the history of the earth? How can it be proved that certain rock formations in various parts of the earth originated at practically the same time? There are two important criteria. First, in many regions where the strata have not been notably disturbed from their normal order, the older strata underlie the younger because they must have been deposited first. Now, the total thickness of the stratified series of the earth is estimated to be no less than 200,000 feet, with only parts of this actually present in given localities or regions. It is, therefore, evident that the order of superposition of strata is in itself not sufficient for the determination of the relative ages of all strata in even a large portion of a single continent, not to mention its utter inadequacy in building up the geological column of the whole earth. When, however, the second criterion, namely, the fossil content of the strata, is used in direct connection with the order of superposition, we have a real basis for determining the relative ages of the strata for all parts of the earth. It has been well established that any given epoch or period of geologic time had a characteristic assemblage of organisms many of which are now found in fossil form in the series of strata which were deposited during that epoch

TABLE OF MAIN GEOLOGICAL DIVISIONS

DURATION IN YEARS (MINIMUM)	ERAS	PERIODS	DOMINANT LIFE
3 to 5 million	Cenozoic	Quaternary Tertiary	Age of man Age of mammals
5 to 10 million	Mesozoic	Cretaceous Jurassic Triassic	Age of reptiles; age of cycad plants; first birds in the Jurassic; first high order modern plants in the Cretaceous
15 to 25 million	Paleozoic	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian	Age of amphibians; great coal age with large, simple non-flowering plants Age of fishes Age of invertebrate animals; very simple forms of plants
?	Proterozoic	Algonkian	Relatively simple forms of life— meager records
?	Archeozoic	Archean	Beginnings of life—no determinable fossils

or period, that is unless the strata have been so notably altered that the fossils have been obliterated. Such obliteration of fossils has taken place in many of the strata of western Massachusetts.

The known history of the earth has been more or less definitely divided into great eras and lesser periods and epochs, constituting what may be called the geologic time scale. In the accompanying table the era and period names, except those representing earlier time, are mostly worldwide in their usage. Epoch names, being too numerous and of local application, are omitted from the table. For a proper understanding of the following pages it is necessary for the reader either to learn this table or to refer to it whenever in doubt concerning one of the names.

VERY ANCIENT (PREPALEOZOIC) HISTORY

The oldest known records of earth history are found in the rocks of Archeozoic age. No rocks representing that exceedingly remote era of geologic time are actually exposed in the Connecticut Valley proper of Massachusetts. They are, however, rather extensively developed at the surface in the Berkshire Hills. The outcrops which lie nearest the Connecticut Valley are five or six miles southeast of Westfield. Geologists are generally agreed that Archeozoic rocks are everywhere present as part of the earth's crust either at the surface or under cover of later rocks, that is that they constitute the universally existant foundation rocks of the outer portion of the earth. We can then be quite certain that Archeozoic rocks much like those of the Berkshire Hills underlie the whole Connecticut Valley though they are there completely concealed under later deposits.

Under what conditions were these most ancient known foundation rocks of the region formed? What was western Massachusetts like during the Archeozoic era? Examination of the outcropping Archeozoic rocks shows them to consist of two general kinds, one a series of stratified or sedimentary rocks which were deposited layer upon layer under water in the form of sands, muds, and limes, and the other igneous rocks which were forced in a molten condition into the earth's crust. Field studies have shown that the igneous rocks, mainly granites, have cut to pieces, penetrated, and even enveloped large and small masses of the Archeozoic strata which proves that the strata were present before the granites were forced in. This leads us to the interesting and important conclusion that the earliest known geographic condition of western and central western Massa-

setts, including the area now occupied by the Connecticut Valley, was a great expanse of water, more than likely part of the sea.

After long ages, during which the strata accumulated under the water, great bodies of molten granite were irregularly forced into the strata but not to the earth's surface. Either accompanying the granite intrusions, or soon after, the whole of western Massachusetts emerged from the water. This inaugurated a long period of profound erosion, that is a long stretch of time during which, as a result of weathering of the rocks and the action of the streams in carrying away the weathered materials, the land was greatly worn down. In fact this erosion cut away enough of the land to lay bare large bodies of granite which had solidified from a molten condition thousands of feet below the surface. This erosion interval must have lasted some millions of years. That it occurred before the beginning of the Paleozoic era is proved by the fact that very early Paleozoic strata have been found resting upon the deeply eroded surface of the Archeozoic rocks.

How old are these Archeozoic rocks? If we attempt to answer this question in terms of years we encounter real difficulties because we have nothing like an exact standard for such measurement or comparison. While it is fully realized that anything like even approximate actual figures cannot be given, a very conservative estimate of the age of the Archeozoic strata would be 50 to 75 million years. In any case the time is utterly inconceivable to us, the important thing to bear in mind being that the great important events of definitely known earth history which have transpired since Archeozoic days required a lapse of many millions of years as shown, for example, by the enormous accumulations of strata (sediments) in many parts of the world; the repeated advances and retreats of the sea over many parts of the continents; the building up and wearing away of many mountain ranges; and many other profound physical changes. The time conception here expressed will be much better appreciated by the reader after he has followed through the story of the Connecticut Valley as set forth in the succeeding pages.

After the Archeozoic came the great Proterozoic era. Basing our knowledge upon the study of rocks of that age in various parts of the world, we may be sure that the Proterozoic era lasted for millions of years. Since no Proterozoic rocks are definitely known to be present in western Massachusetts the records of that era are there lacking. If any strata of that age ever were formed in the western part of the state they have either been completely removed

by erosion or they lie concealed under later (younger) rocks. More than likely the whole district, including the site of the Connecticut Valley, persisted as a land area during Proterozoic time and underwent the profound erosion as above described.

PALEOZOIC HISTORY

Cambrian and Ordovician Periods

After the lapse of inconceivably long eons of geologic time the great Paleozoic era was ushered in. As we have learned, the records of events in central western Massachusetts prior to the Paleozoic are relatively scant, but our knowledge of the history of the region during Paleozoic time is much more detailed. Even in this case, however, many of the rocks have been so notably altered from their original condition that certain of the records are distinctly more obscured and difficult to read than those of Postpaleozoic time. Paleozoic rocks of various kinds and ages are extensively exposed at the surface in the uplands on either side of the Connecticut Valley (see map figure 10) and in the Berkshire Hills.

The first period (Cambrian) of the Paleozoic era was inaugurated in western Massachusetts by a submergence of the whole region under the sea. With one or two possible interruptions, the sea continued to overspread the region, more than likely including the site of the Connecticut Valley, throughout most of Cambrian and Ordovician times (see above table of geologic time). In that sea there accumulated a great thickness of stratified rock materials. At the very bottom, and resting upon the eroded surface of the Archeozoic rocks, there is an altered bed of conglomerate hundreds of feet thick representing an ancient gravel beach deposit of the Cambrian sea. This is called the Dalton formation. Next above this comes an altered sandstone—the Cheshire formation. Then comes the thick formation of the Stockbridge limestone, or rather marble, so extensively developed in the Housatonic Valley. This marble is partly Cambrian and partly Ordovician in age. A whole series of Ordovician rock formations called “schists”, including the Hoosac, Rowe, Savoy, and Hawley schists, rest upon the Stockbridge marble. These schists were original sea muds which first hardened into “shales” and then, under conditions of heat, pressure, and moisture were crystallized and altered into “schists”. Most of the schists are rich in flakes of mica (“isinglass”) which cause them to have a shiny appearance. These early Paleozoic strata were piled layer

upon layer on the floor of the sea to a thickness of thousands of feet, and it must have taken some millions of years to complete the pile. None of these formations are exposed in the Connecticut Valley proper, but several of the upper (Ordovician) ones are well shown in the upland just west of the valley from Westfield, and also in the northern upland in the vicinity of Charlemont. The youngest one of all (Hawley schist) forms an oval shaped area at the top of the large hill between Chesterfield and Goshen where it reaches the earth's surface from under later formations. The areas of the Ordovician rocks are shown on the geologic map (figure 10). It is practically certain that rocks of the same age much like those just described lie under the whole Connecticut Valley of Massachusetts.

How does the geologist know that these rocks were formed during the early Paleozoic era? By way of brief answer to this question two principles are involved, first, that, in any mass of stratified rocks not too severely disturbed from their original position, the oldest or first formed strata lie at the bottom and succeeding (younger) ones are higher up, and second, that each group of strata, beginning with the early Paleozoic and not too profoundly altered, contains fossil shells or imprints of organisms characteristic of the time when the strata accumulated. Now the strata in question all rest upon the eroded surface of Prepaleozoic rocks and underneath later Paleozoic (Silurian) rocks, and certain of the strata, especially the Stockbridge limestone or marble, actually contain fossils known the world over to be characteristic of early Paleozoic time.

Early Paleozoic Mountain Making

We are now ready to consider one of the grandest events in the geological history of western Massachusetts. Toward the close of the Ordovician period a tremendous compressive force in the earth's crust, caused by shrinkage of the planet, was brought to bear upon the pile of strata which had accumulated on the floor of the Cambrian and Ordovician seas over western Massachusetts. As a result of this compression the strata were tilted, highly folded, and elevated into a mountain range which has been called the Taconic Mountains. It should not be presumed that the force which folded and upraised the Taconic Mountains accomplished its work suddenly. Slowly and irresistibly, through much of a geologic period of time, the force was applied and the mass of strata was gradually bulged and bent well below the surface and fractured at and near the surface. It

should be clearly understood, however, that the present Berkshire Hills are only recently reëlevated remnants of the once grand Taconic Mountains as explained beyond. There is no direct evidence that the site of the Connecticut Valley proper was notably affected by this folding, though it was quite certainly somewhat elevated as the eastern flank of the Taconics.

How do we know that the Taconic disturbance took place toward the close of the Ordovician period? In the first place, the folding must have occurred after most of Ordovician time had passed because middle to late Ordovician strata are involved in the folding. This is best proved in eastern New York where it is possible to definitely prove the age of the rocks by the fossils contained. In the second place, the folding must have been completed before middle Silurian time because strata of that age rest upon the worn down (eroded) surface of the folded rocks. In this way the geologist actually determines what may be properly called the geological birthday of the mountain range.

Silurian History

Coming now to a consideration of the next (Silurian) period we are dealing with a chapter of the long Paleozoic era which has a very direct bearing upon the history of central western Massachusetts because rocks of this age are extensively developed at and below the surface in the upland region west of the Connecticut Valley. There are two main formations of this age—an older and therefore underlying formation called the Goshen schist, and a younger overlying formation called the Conway schist. These are so named from the villages of Goshen and Conway near which typical outcrops of the rocks may be seen. These two formations occupy most of the upland country, forming a belt 10 to 15 miles wide west of the floor of the Connecticut Valley (see map figure 10). The Conway schist, being younger, is more widespread as a surface rock than the Goshen schist. Both formations quite certainly pass under all or nearly all of the valley.

The Goshen and Conway schists were originally muds and muddy sands with some limes which were deposited layer upon layer under sea water which spread over the area during Silurian time. Fossils of Silurian age have been found in strata judged to be northward continuations of the Goshen and Conway schists in Vermont and New Hampshire. As a result of the mountain building processes



FIG. 5. AN OUTCROP OF THE CONWAY FORMATION REPRESENTING NOTABLY ALTERED MUDS AND LIMES WHICH WERE ORIGINALLY DEPOSITED ON A SEA FLOOR AT LEAST TWENTY MILLION YEARS AGO DURING THE SILURIAN PERIOD OF THE PALEOZOIC AGE. THE LIGHTER PORTIONS ARE NOW SCHISTS AND THE DARKER LAYERS ARE IMPURE LIMESTONES. BY THE STATE ROAD BETWEEN DEERFIELD AND CONWAY. PHOTOGRAPHED BY THE AUTHOR.

which took place late in the Paleozoic era (see beyond) these old Silurian sea muds were hardened and crystallized into the present schists which consist mostly of the common minerals, quartz, feldspar, and mica. These schists generally split readily into plates or thin layers the surfaces of which, on account of the abundance of mica flakes, are very shiny. They usually contain considerable graphitic matter (so called "black lead") which represents the crystallized remains of very ancient organisms. Small red garnet crystals may be seen in many parts of these formations. These garnets have resulted from the crystallization of certain ingredients of the ancient sea muds.

Locally some narrow beds of dark gray impure limestone lie within the Conway schist, especially in the eastern and northern portions of the area. They are excellently exhibited in parts of the Whately Glen and in a ledge by the main road about 2 miles east of Conway (see figure 5). "In many places these (limestone) beds are changed above and below for 2 or 3 inches into hornblende schist, and when blocks are separated from the ledge they weather in swampy places into forms like plowshares, anvils, and the like from the solubility of the limestone."—Emerson. Good specimens of these curious forms of rock may often be seen in door yards, two having been placed at the north entrance of College Hall, Smith College. Throughout the Conway formation there are also many bands or layers rich in quartz, these representing original deposits of sands and sandy muds.

Because of the highly altered character of the Goshen and Conway schists, the thickness of the original pile of strata which they represent is difficult to estimate but quite certainly it is no less than several thousand feet.

A third formation of Silurian age is the Leyden slate which rests upon the Conway schist. It is much less extensively developed than the Conway schist in Massachusetts, but it is widely exposed in Vermont where slate quarries have been operated in it. It is the surface rock over most of the town of Leyden north of Greenfield, the only other area being a narrow belt reaching from Whately southward nearly to Leeds. This rock was also an original sea mud, but it has not been as highly altered (metamorphosed) as the Goshen and Conway schists. It has been only partially crystallized, but as a result of subjection to pressure the rock has been locally corrugated with accompanying development of slaty cleavage. This

latter phenomenon is perfectly shown in the ledges just west of Whately village. The thickness of the Leyden formation is only a few hundred feet.

The Silurian sea in which the muds and sandy muds, now represented by the Goshen, Conway, and Leyden formations, were deposited appears not to have spread over either the Berkshire Hills region or central or eastern Massachusetts. Based upon geological studies in this state and elsewhere in New England, in New York, and in the St. Lawrence Basin, we have good reason to think that the Silurian sea overspread only the central western part of the state including the site of the present Connecticut Valley, and that this sea was the narrow southern extension of marine waters which were widespread over the general St. Lawrence area. The sediments which accumulated on the floor of this arm of the sea were derived from the wearing down (erosion) of the lands in western and central Massachusetts and carried into the sea by rivers. As shown by the nature of the original strata (muds and sands), the sea water in which they were deposited must have been relatively shallow. But on account of the great thickness of the strata—at least several thousand feet—we are forced to conclude that the floor of the arm of the sea slowly sank as the accumulation of strata took place. In this connection it is of special interest to note that we here have the earliest known evidence of the tendency of the earth's crust to sag, forming a structural basin, across this part of the state. As pointed out beyond this tendency of the general Connecticut Valley area to sag has been a very strong one during the many millions of years from Silurian time almost to the present. It should not, however, be thought by the reader that the Connecticut Valley of the present day is a direct result of the Silurian structural basin. The origin of the existing valley is geologically recent as shown in the following pages.

Devonian History

During late Silurian and early Devonian times the land was sufficiently elevated to cause the disappearance of the arm of the sea of earlier Silurian time. This is clearly indicated by the fact that middle or upper Devonian strata in the northern part of the Connecticut Valley of Massachusetts rest upon the eroded (worn down) surface of the Silurian rocks. During this time of erosion the region was, of course, land.

In the middle of the great Devonian period the structural basin

across central western Massachusetts was restored in part at least and sea water again came in. Positive evidence that the Devonian sea spread as far south as the vicinity of Greenfield consists in the fact that strata containing the shells (fossils) of marine animals characteristic of middle to late Devonian time extend from a few miles north of Greenfield through Vermont and into the St. Lawrence Gulf region. A considerable area of these rocks occurs in the vicinities of Bernardston and Northfield (see map figure 10). These rocks are strata consisting of notably altered (metamorphosed) sandstone, shale, and limestone, but the alteration has not been great enough to completely obliterate the fossils as has been the case with the underlying Goshen and Conway formations. Some of the fossils, consisting mainly of corals, crinoids, and brachiopods, may be found in a bed of the limestone in an old quarry about 1 mile north of Bernardston.

By their very nature we can be sure that these strata once extended considerably farther south over the Connecticut Valley district, and that they have since been removed by erosion. In view of the fact that marine strata of exactly the same age as the Bernardston strata are conspicuously developed in southeastern New York it is at least highly probable that an arm of the Devonian sea spread over all or nearly all of the Connecticut Valley area in Massachusetts and connected the broad marine waters of the Gulf of St. Lawrence region with those of southern New York.

Recent studies have shown that, toward the close of the Devonian period, the whole region from southern New England to the Gulf of St. Lawrence was notably affected by earth crust disturbances of uplift. At that time the Devonian sea was expelled from western New England.

Strata of Later Paleozoic Age

Strata of Paleozoic age later than the Devonian are, according to Professor Emerson, present on the eastern side of the Connecticut Valley. Most important is the formation called the Amherst schist which is considered to be a western more highly altered representative of extensively developed strata of the same age in central Massachusetts. In the vicinity of Worcester these strata contain fossil land plants which grew during the great Coal Age or Pennsylvanian period. In many places the more highly altered of these rocks contain graphite (socalled "black lead") which represents metamorphosed organic

matter, probably plant remains. During all the geological work which has been carried on in New England and New York no evidence has ever been produced to show that true marine waters spread over those areas during late Paleozoic time. There is no evidence from the strata themselves in central Massachusetts that they were formed under the sea. In fact the presence of land plants leads us to the opposite conclusion, namely, that they accumulated as terrestrial deposits on river flood-plains, in lakes, and in great swamps where plant life was prolific. During this same time—the Pennsylvanian or Coal Age—in the Mississippi Valley and Appalachian Mountain regions there were vast areas of lowlands, often swampy, upon which sediments accumulated and plants grew in great profusion, remains of the latter having since been changed into the great coal beds. The very hard anthracitic coal of Rhode Island is of the same age and origin.

It is difficult to say how far west of their present outcrops these late Paleozoic strata once extended in Massachusetts, but it was probably not far. Quite certainly they do underlie the later rocks of the Connecticut Valley to some extent on the east side. The mass of late Paleozoic schist on which Amherst and Mount Warner are situated (see map) is now exposed because the late covering of early Mesozoic (Triassic) strata has there been removed by erosion, a small isolated body of the later strata still remaining east of Amherst village.

Appalachian Mountain Revolution

One of the most profound and far reaching physical disturbances in the history of eastern North America took place toward the close of the Paleozoic era. It has been called the Appalachian Revolution because at that time the Appalachian Range was born out of the sea by folding and uplift of the strata. It would be more accurate to say that the revolution reached its climax at about the close of the Paleozoic because premonitory crustal movements occurred several times long before the close of the era. In central western Massachusetts there were, for example, considerable uplifts toward the close of both the Silurian and Devonian periods as already described. But the grand climax was reached very late in the Paleozoic era and very early in the Mesozoic era. The date of the disturbance is clearly established by the fact that nonfolded relatively early Mesozoic (Triassic) strata rest upon highly folded late Paleozoic

strata in Nova Scotia, New Brunswick, the Connecticut Valley, and on the eastern side of the Appalachian Mountains from New Jersey to Virginia.

The greatest force of the revolution affected the region from the Gulf of St. Lawrence to central Alabama where much folding and elevation of the rocks took place. Even where the rocks were not notably folded throughout much of the eastern half of the continent, more or less uplift of the land took place, this having been true of the Allegheny Plateau district just east of the Appalachians and also of northern and western New York. One main zone of folding reached from southeastern New York to Alabama, and another through eastern and central western New England. The notable folding of the strata on each side of the Connecticut Valley as shown by structure section figure 9 took place at that time. Perhaps the finest large scale example of such folding in central western Massachusetts is the great upbend (anticline) in the strata between Williamsburg and Cumington, the crest of the eroded anticline now occupying the top of the Chesterfield-Goshen ridge. This broad very distinct fold is clearly indicated by figure 9.

The Berkshire Hills region, which had been highly folded and upraised into the Taconic Mountains toward the close of the Ordovician and then considerably cut down and somewhat rejuvenated a time or two by uplift in later Paleozoic time, was probably not much affected by the Appalachian Mountain folding, but more by pronounced uplift.

Between the highly folded and upraised regions of western and central Massachusetts, or, in other words, the general area of the Connecticut Valley, there was a broad structural basin or intermontane valley where the rocks were folded but relatively less upraised than on either side. We have already noted that, during much of Paleozoic time, there was a marked tendency for this very district to sag below the country on either side, even to the extent of admitting sea water on two occasions. This great late Paleozoic structural basin has a very important bearing upon the later history of the Connecticut Valley district as pointed out in the first part of the next chapter.

There were two other important accompaniments of the Appalachian Revolution in the central western part of the state. One was the alteration or metamorphism of the strata of Postordovician age at least. The other was the forcing of large volumes of molten rock into the strata. As already mentioned in the description of the

strata ranging in age from Silurian to late Paleozoic, these rocks are no longer in their original condition as muds, sands, and limes, but they first hardened into shales, sandstones, and limestones, and then they were metamorphosed into schists and slates, quartzites, and crystalline limestone or marble. All evidence points to the conclusion that the metamorphism took place when the rocks now at the surface were more or less deeply buried, and that they were subjected to heat and high pressure during the Appalachian Mountain making disturbance. The rise of the molten rocks (below described) no doubt contributed enough heat to aid in the crystallization of the strata.

How do we know that the schists and other altered strata now at the surface were once well below the earth's surface? In the first place, it has been well established both by field work and experimental methods that strata can be conspicuously folded only when they are under a considerable load of overlying material, and that rocks relatively near the surface yield to pressure by being broken (faulted). A great fold, therefore, like the Goshen-Chesterfield anticline, is now exposed to view only because of removal of much overlying material by erosion. In the second place, geological studies have established the fact that igneous rocks like granite which we now see at the surface, and which were forced into the strata in molten condition, must have cooled well below the surface.

Rise of Molten Rocks into the Strata

As suggested just above, great volumes of molten rock were forced upward into the earth's crust as a general accompaniment of the Appalachian Revolution. In the folding and uplift of mountain ranges at various times in many parts of the world during the application of the tremendous force of lateral compression, due to earth shrinkage, it has been a common thing for the terrific downward pressure of overlying rocks miles thick to be sufficiently relieved so that deeply buried hot, but not molten, rocks finally become liquid and are then crowded upward toward and even to the earth's surface by the lateral mountain making pressure. It is seen, therefore, that it is not at all necessary to assume a molten earth's interior to explain the intrusion of molten rocks.

Various large and small bodies of such igneous (once liquid) rocks are now exposed on either side of the Connecticut Valley in the uplands. The principal rocks represented are granite and a



FIG. 6. DETAILED VIEW OF THE GRANITE, OR RATHER DIORITIC GRANITE, IN THE CITY QUARRY IN NORTHAMPTON. THIS ROCK WAS FORCED INTO THE EARTH'S CRUST IN MOLTEN CONDITION DURING LATE PALEOZOIC TIME AT LEAST TEN OR TWELVE MILLION YEARS AGO. THE NARROW WHITE BANDS ARE "DIKES" WHICH RESULTED FROM THE FILLING OF FISSURES IN THE GRANITE BY SOMEWHAT LATER MOLTEN MATERIAL. THE CRACKS, KNOWN AS "JOINTS," ARE GENERALLY COMMON IN HARD ROCK FORMATIONS. PHOTOGRAPHED BY THE AUTHOR.

related type called diorite. The main areas are indicated on the geological map (figure 10). Many ledges of the typical rocks may be seen in all of the larger areas as, for example, the one west of Northampton. Most of the rock is a light gray, medium-grained, homogeneous granite consisting mainly of feldspar, and quartz with scattering flakes of glistening mica. A common phase of the general granite bodies is darker gray, less rich in quartz, and with considerable black mica and dark hornblende. This darker (dioritic) rock shows well just west of the main road north of Northampton especially in the large city quarry (see figure 6).

It is highly probable that at least small masses of these great bodies of molten rock were forced all the way to the surface through active volcanoes, because molten lavas are generally supplied from subterranean reservoirs of liquid rock. Any such volcanoes have, however, long since been worn away (eroded) so that not a single volcanic site can be made out today.

That the granite was forced into the strata while molten can be

proved beyond the shadow of a doubt. In many places small and large tongues of the granite may be seen cutting the strata (now schists) in all directions. Large scale examples of such tongues are shown as offshoots of the body of granite lying between Goshen and Conway as indicated on map (see figure 10). Many very narrow tongues of granitic material cut the strata parallel to the original layer (see figure 8). In some cases certain minerals have crystallized in the schists only close to the granite contacts on account of the heat. This is finely illustrated where the Leyden slate formation lies against the granite between Whately and Leeds. In many other places the once molten intrusive nature of the granite is proved by the presence in it of large and small fragments of the schists, the



FIG. 7. A LEDGE OF DECOMPOSING AND CRUMBLING GRANITE BY THE RAILROAD BETWEEN LEEDS AND HAYDENVILLE. THE ROUNDED MASSES ARE CORES OF STILL RELATIVELY FRESH GRANITE. PHOTOGRAPHED BY THE AUTHOR.

molten material in such cases having cut to pieces and enveloped portions of the schists. Very fine examples of such enveloped fragments of schist may be seen in the ledges of granite along the electric car line between Leeds and Haydenville. These are all fragments of the Conway schist which occupied this entire district before the granite was forced up. At the southern end of these ledges

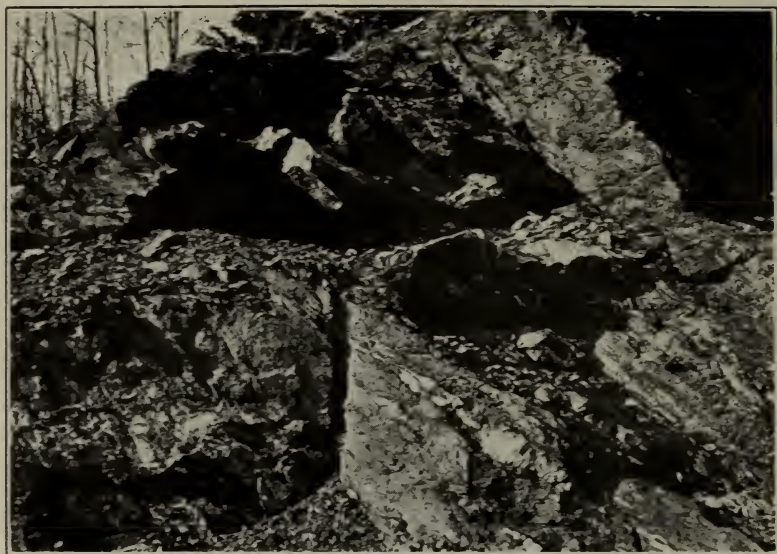


FIG. 8. AN OUTCROP OF THE CONWAY SCHIST FORMATION MORE OR LESS INJECTED WITH GRANITE (THE WHITE LENSES AND LAYERS) PARALLEL TO THE NOW INCLINED STRATIFICATION OF THE SCHIST. THE INJECTION TOOK PLACE MILLIONS OF YEARS AGO IN LATE PALEOZOIC TIME. BY THE STATE ROAD EAST OF CONWAY. PHOTOGRAPHED BY THE AUTHOR.

near Leeds a lens, a few feet long, of baked nearly white limestone, formerly a part of the Conway formation, may be seen included in the granite.

Another feature of interest which must attract the attention of even the casual observer of the granites is the presence in them of more or less sharply defined, mostly nearly vertical, coarse-grained, nearly white belts or bands of rock. Excellent examples occur, among many other places, in the ledges between Leeds and Haydenville, and about half way between Leverett and Montague. These are good illustrations of what are known as "dikes", that is they represent fissures which were filled with molten rock material. These dikes in the granite may be explained as follows. After the great mass of molten granite came to rest or almost so, and cooled enough to solidify, cracks developed in it because of contraction and still molten rock of slightly different composition was forced from a lower level upward into the cracks there to cool. The crystals of feldspar, quartz, and mica in these dikes are commonly large, ranging from one-half of an inch to several inches across. Such coarse-grained dike

material is called "pegmatite". Another kind of dike found in the granite is as fine-grained as the granite or more so, white to pink, and consists almost wholly of feldspar and quartz. A multitude of such dikes, seldom more than a foot wide, may be seen cutting through the dark phase of the granite in the city quarry just north of Northampton (see figure 6). These are known as aplite dikes. In many places dikes of both kinds have also been forced into the adjacent schists, an extra good place to observe the phenomenon being on Mount Warner across the river from Hatfield where the late Paleozoic schist is full of dikes of various sizes. In some cases one kind of dike may there be seen cutting across another, thus proving that they were forced in at different times. Many years ago an attempt was made to mine mica ("isinglass") in one of the large coarse-grained pagmatite dikes at the south end of Mount Warner. In this dike the mica, which splits into exceedingly thin sheets, occurs in numerous clear crystals 1 or 2 inches in diameter.

Landscape and Rocks of very Late Paleozoic Time

Before proceeding to a discussion of the important events of the early Mesozoic history the reader should have in his mind a clear picture of what central western Massachusetts was like in very late Paleozoic time. What was the landscape like, and what rocks were at and below the surface? The granites which we now see at the surface were then far down; the schists of Paleozoic age were then not nearly so deeply cut into by erosion as at present; and a great valley or basin occupying the site of the present Connecticut Valley was then well developed; mountainous highlands far loftier and more rugged than the existing hills lay on either side of the valley; and the great mass of early Mesozoic strata had not yet accumulated in the basin. The mountains, which were the direct result of the Appalachian Revolution, have been called the New England Alps.

MESOZOIC HISTORY

Earlier Triassic History (the Mountains Cut Down)

Just as the records of the Paleozoic era are much more clearly shown than those of the Archeozoic in central western Massachusetts, so the Mesozoic records are distinctly clearer than those of the Paleozoic. Not only are the main features of Mesozoic time well

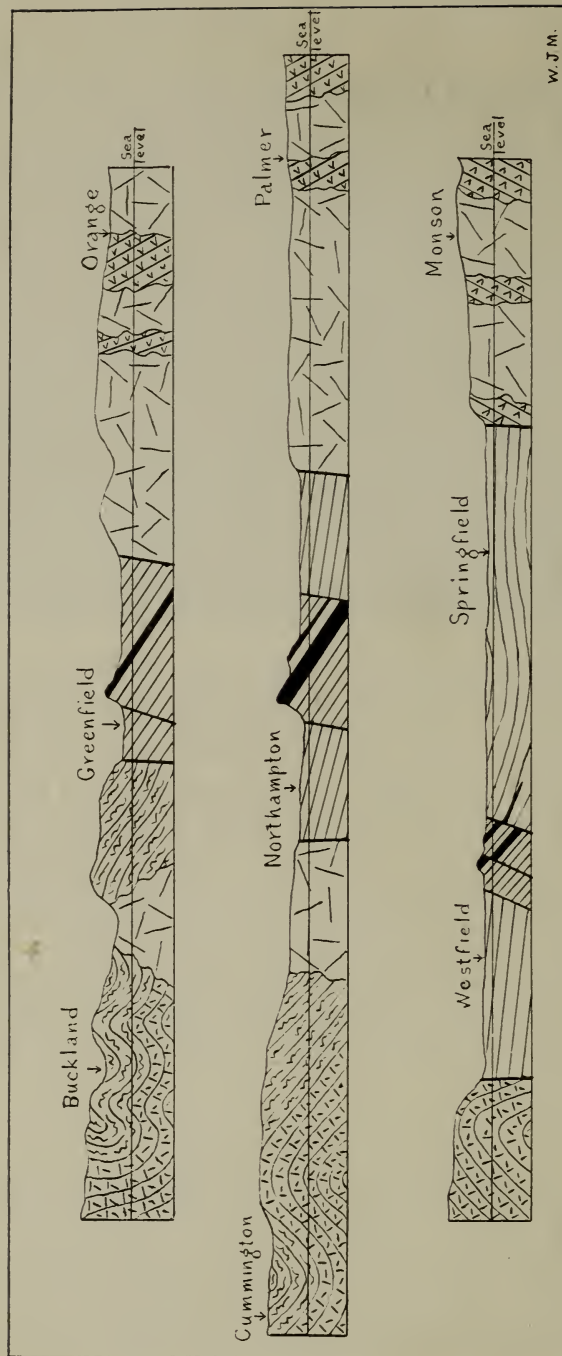


FIG. 9. STRUCTURE SECTIONS SHOWING THE GENERAL RELATIONS OF THE ROCKS OF CENTRAL WESTERN MASSACHUSETTS AS THEY WOULD APPEAR ON THE FACES OF VERTICAL SLICES THROUGH THE EARTH'S CRUST ALONG THE LINES OF THE PLACES INDICATED. VERTICAL SCALE EXAGGERATED. SYMBOLS FOR ROCK FORMATIONS ARE THE SAME AS ON THE ACCOMPANYING GEOLOGIC MAP (FIG. 10) WHICH SHOWS THE SURFACE DISTRIBUTION OF THE FORMATIONS. DRAWN BY THE AUTHOR.

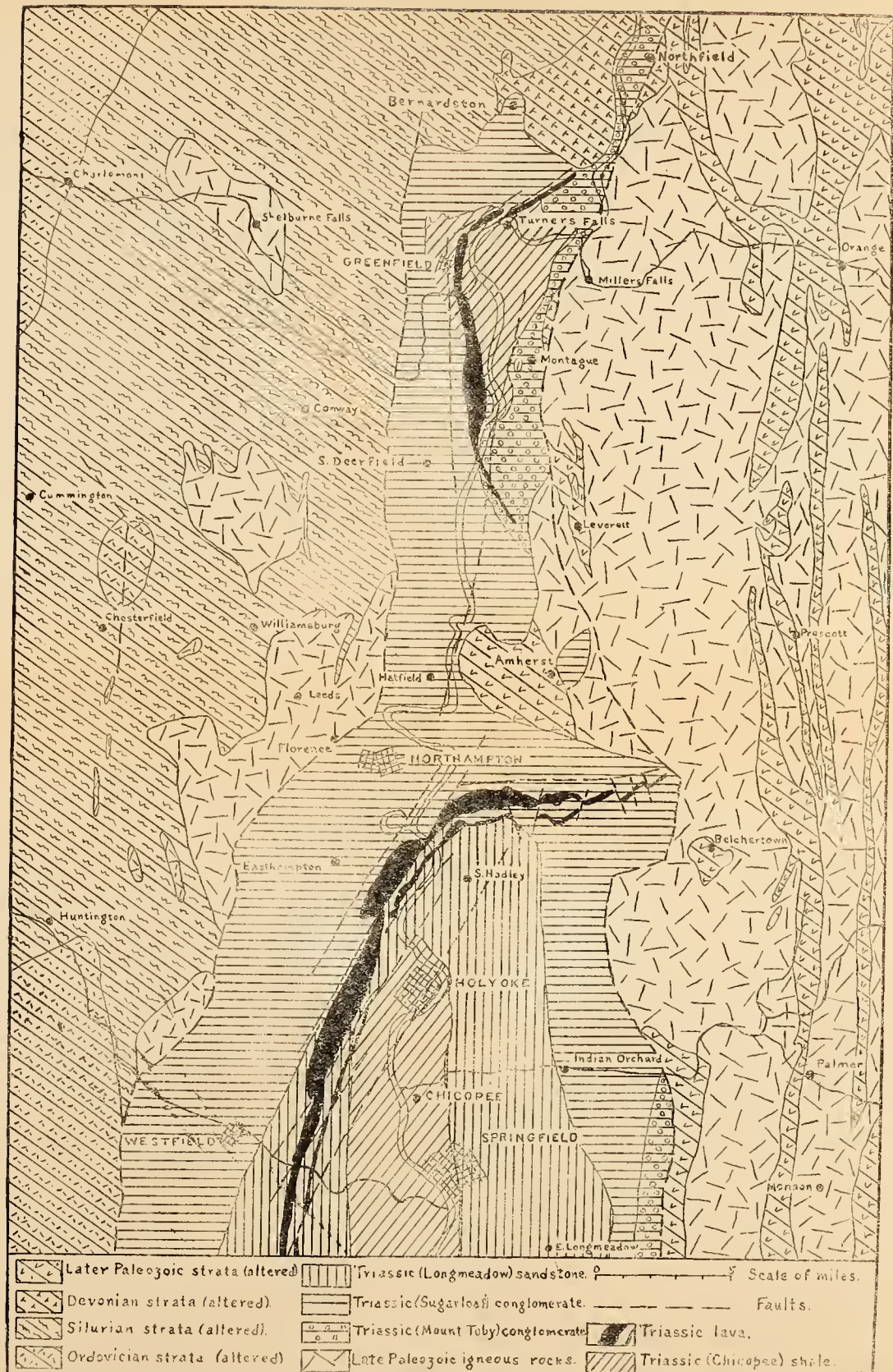


FIG. 10. GEOLOGICAL MAP OF CENTRAL WESTERN MASSACHUSETTS SHOWING THE SURFACE DISTRIBUTION OF THE PRINCIPAL ROCK FORMATIONS, GENERALIZED AND SIMPLIFIED FROM THE STATE MAP MADE BY PROFESSOR B. K. EMERSON. DRAWN BY THE AUTHOR.

known, but also many details of the history covering late Triassic time are recorded with an amazing degree of perfection, some of these being pointed out below.

We are now ready to consider the opening of the great Mesozoic era beginning with the Triassic period at least 8 or 10 million years ago. During the first half or two-thirds of Triassic time vigorous erosion or cutting down of the mountainous lands took place in central western Massachusetts. The thick, highly folded Paleozoic strata and involved granites, during this time at least 1 or 2 million years long, slowly weathered and crumbled, and the loosened materials were carried away by the streams. This process of erosion went on until, by relatively late Triassic time, the strata were deeply cut into and worn down, granite bodies were laid bare, and the probably once existing volcanoes were completely eradicated. The derived sediments were carried far away, probably into the Atlantic Ocean. In any case they certainly are not present in central western Massachusetts, and they have never been found anywhere.

How can we tell that so much erosion took place during the early and middle Triassic period? The answer to this question involves an important method of geological reasoning. First, as we have already established, the late Paleozoic strata were folded and the granites were intruded toward the close of the Paleozoic era, which means that the erosion must have taken place still later. Second, late Triassic strata, as below described, have been found to rest upon the deeply eroded late Paleozoic rocks, which fact proves that the erosion took place before the late Triassic sediments were deposited.

Later Triassic History

Accumulation of Strata in a Sinking Basin. By later Triassic time the high mountainous landscape of central western Massachusetts had been notably subdued and the north-south structural basin or trough was less conspicuous. The basin then lay near sea level so that drainage from it was much more sluggish. Sediments derived from the continued erosion of the highlands on either side then began to accumulate in the wide basin or valley. But once again the periodic weakness of this part of the earth's crust became manifest and the basin began to sink. Soon this sinking lowered the floor of the basin or trough enough so that the stream (or streams) from it was no longer able to transport all of the sediments which were

carried into it from the highlands on either side. Most of the sediments, therefore, began to spread over the floor of the basin and pile up layer upon layer more or less irregularly. This great subsiding trough extended north and south all the way through Massachusetts and Connecticut. Between Northampton and Springfield the basin was at least 15 to 20 miles wide, while from Northampton to the Vermont line it was at least 6 to 8 miles wide. It was fully as wide as the area of Triassic strata shown on the geologic map (figure 10).

During this late Triassic time the floor of the basin slowly settled at least $1\frac{1}{2}$ to 2 miles, and in the meantime sediments kept piling up on the sinking floor. What is the nature of the evidence which leads us to this remarkable conclusion? The evidence is twofold, based upon the great thickness of the strata and their character. These Triassic strata comprise three more or less distinct formations. One is a conglomerate or sandy conglomerate (cemented mixture of sand and gravel) called the Sugarloaf formation because of the excellent display of the rock in South Sugarloaf Mountain near South Deerfield. A local phase of this formation is known as the Mount



FIG. 11. AN OUTCROP OF THE SUGARLOAF SANDY CONGLOMERATE FORMATION AS SEEN TOWARD THE TOP OF SOUTH SUGARLOAF MOUNTAIN. THIS ROCK IS OF TRIASSIC AGE, OR AT LEAST EIGHT MILLION YEARS OLD. MANY PEBBLES AND SMALL BOULDERS ARE EMBEDDED IN THE RED SANDSTONE MATRIX WHICH IS ONLY CRUDELY STRATIFIED. PHOTOGRAPHED BY THE AUTHOR.

Toby conglomerate. A second is mostly thin layers of sandstone associated with some beds of shale. It is called the Longmeadow formation because of fine exposures of the rock in the quarries near East Longmeadow. A third is mostly shale (hardened mud) named the Chicopee formation. Between Northampton and Springfield all three of these formations occur, and their total thickness is at least $1\frac{1}{2}$ to 2 miles.

The very coarseness of grain and crudely stratified character of the Sugarloaf conglomerate, and the common occurrence of ripple-marks and tracks of land animals throughout the Longmeadow sandstone, conclusively prove that the materials of these two thick formations must have been deposited layer upon layer under very shallow water of intermittent or shifting character. We are, therefore, forced to conclude that more or less steady sinking of the basin took place while the sediments accumulated. More than likely the very weight of the piling up sediments aided the downsinking process. It might reasonably be argued that the load of depositing sediment actually caused the sinking of the basin, while the lands on either side slowly rose because of diminution of the load there due to removal of the rock materials by erosion.

The Sugarloaf sandy conglomerate is the most extensively developed of the three Triassic formations. As shown on the map (figure 10) it is the most widespread bedrock of the valley. Its color, due to the abundance of red oxide of iron, is almost always red as is remarkably well shown in Sugarloaf Mountain (see figure 11). Another excellent exposure is the big ledge by the road at Mount Tom Junction where the tilted layers show the crude stratification so characteristic of the formation. It may be of interest to note that this sandy conglomerate of Triassic age is the bedrock which underlies the main parts of the cities of Northampton and Westfield, the rock in each place being mostly covered by unconsolidated Glacial and Postglacial deposits.

Even a casual examination of the Sugarloaf formation affords a very interesting and conclusive lesson as to its origin. In the ledge at Mount Tom Junction, for example, one may find fragments of the schists, granite, and even pegmatite of Paleozoic rocks like those which now outcrop in the hills west of Northampton. It is very clear that, during the latter part of the Triassic period, the products of weathering of the Paleozoic rocks were swept from the highlands by streams well out into the great basin. Many of these fragments range in size from one to several inches which proves that the streams

carrying them along must have been swift, and this in turn means that the streams flowed from mountainous highlands over steep valley sides.

The Sugarloaf conglomerate formation is thousands of feet thick, probably 1 mile at the very least. A well drilled in Northampton many years ago to a depth of 3,700 feet showed the presence of Sugarloaf sandy conglomerate all the way down except the upper 150 feet. Since the strata drilled into are only slightly tilted, and the upper portion of the formation has long since been removed by erosion, and the drill did not reach its bottom, it is certain that the formation is considerably thicker than the depth of the well. The fact that this remarkable formation of such great thickness was so extensively deposited over the floor of the basin, especially along its sides, is of particular significance because it shows that the high steep sides of the valley must have maintained their height either by slow sinking of the basin, or elevation of the uplands, or both.

A remarkable local phase of the Sugarloaf formation is called the Mount Toby conglomerate so named from Mount Toby in which it is extensively developed. It is an exceedingly coarse rock consisting of fragments which are very largely schist, commonly ranging in size from 1 or 2 inches to several feet across. A crude stratification may be observed in parts of the formation. Some layers of sandy material occur in it. The great ledges of the mountain are impressive sights. To understand the origin of this material one must think of very swift intermittent streams, under conditions of semiarid climate, rushing from notable highlands just to the east during late Triassic time. At each time of flood such streams carried large quantities of gravel and boulders to the floor of the basin. Thus the great accumulations of very coarse conglomerate were formed. As explained beyond, Mount Toby has been sculptured out of this formation in comparatively recent geologic time.

From the vicinity of South Hadley a broad belt of the Longmeadow sandstone formation extends southward on each side of the river to the state line. This formation appears to have been to a considerable extent at least contemporaneous in origin with the Sugarloaf conglomerate as shown by the fact that in certain places the one formation has been seen to grade into the other, the finer materials having been carried farther out into the subsiding basin. It seems quite clear, however, that at least the upper part of the Longmeadow formation (total thickness fully several thousand feet) was once considerably more extensive than now between Northampton



FIG. 12. A BIG EXPOSURE OF THE LONGMEADOW SANDSTONE FORMATION OF TRIASSIC AGE AT MOUNTAIN PARK. THE ROCK IS PERFECTLY STRATIFIED IN THIN LAYERS, PROVING THAT IT WAS DEPOSITED UNDER WATER. PHOTOGRAPHED BY THE AUTHOR.

and Springfield. In other words, it lapped over upon the Sugarloaf conglomerate on all sides for some distance but has since been removed by the profound erosion to which the region has been subjected since Triassic days. The rock is mostly a typical sandstone showing perfect stratification usually in thin layers (see figure 12). Local portions of the formation are shales and sandy shales. Many of the layers are covered with numerous glistening flakes of mica ("isinglass") which were derived from the weathering of the older Paleozoic rocks of the highlands. The color varies from gray through brown to red. Many layers contain ripple-marks, ancient mud-cracks, raindrop impressions, and tracks of land animals showing not only that the waters in which the sands and sandy muds were deposited must have been shallow, but also that frequently the surfaces were exposed to the sun. Excellent outcrops may be seen along the river half way between Holyoke and Smiths Ferry, in Mountain Park, and in the stone quarries near East Longmeadow. It is the bedrock underlying the eastern half of the city of Springfield.

Least extensively developed of the three Triassic formations is the Chicopee shale. One area extends from Holyoke southward

into Connecticut as a belt several miles wide forming the bedrock under Holyoke, Chicopee, and the western half of Springfield. At the great dam in Holyoke, and along the railroad opposite the dam, good outcrops show the rock to be limey to sandy shale in perfectly stratified thin layers. Ripple-marks, mud-cracks, and raindrop impressions occur on some of the layers. At Chicopee and Mittineague the rock consists of red shales associated with some thin limey layers. The other area (see map) extends southward for a few miles on either side of the Connecticut River from Turners Falls. Both Turners Falls and Greenfield are underlain with this formation which is in most respects like that of the Holyoke-Springfield area. It is practically certain that the Chicopee shale was once notably more extensive than at present. In fact there is good evidence in support of the view that it originally covered much of the valley floor, at least as a broad central belt across the state. Its fine-grained character, limey layers, and perfect stratification all point to its origin as a deposit in relatively quiet water. The presence in it of ripple-marks, mud-cracks, and raindrop impressions show, however, that the water was shallow and more or less intermittent over the district.

Development of the Great Triassic Basin. We have already shown how the nature of the strata and their great thickness force us to conclude that they must have accumulated in a broad basin or trough which slowly sank thousands of feet. We have also shown that a broad basin, occupying the site of the present Connecticut Valley, lay between high mountains which were produced by the Appalachian Mountain disturbance near the end of the Paleozoic era, and that by relatively late Triassic time both the mountains and the valley were notably cut down by erosion. Then a slow but more or less intermittent sinking of the basin began, and the sediments brought by streams from the uplands on each side began to pile up on the low level subsiding floor. At first the sinking of the basin floor was probably a slow downwarping process such as is known to have taken place in many districts during geologic time, a good case in point being "the Gulf of Bothnia, at the head of the Baltic, where the water appears to lie in a shallow downfold of a well denuded (eroded) old land between upraised areas in Finland and Scandinavia"—Davis. In the opinion of the writer this original downbending of the Triassic basin of central western Massachusetts is best explained as a continuation of the Appalachian Mountain folding process, this view being supported by the fact that all of the several Triassic basins of sedi-

mentation from Nova Scotia to North Carolina exactly follow the trend of the Appalachian folds. As the trough sank the adjacent lands were rejuvenated by elevation. Streams entering the basin from the growing highlands were renewed in activity and they carried loads of coarse material which began to accumulate on the floor of the basin only after it had sunk so far that drainage from it was unable to carry away the sediments as fast as they were brought in. The load of accumulating sediments must have aided or accentuated the downbending process. According to this view, deposition of at least some sediment would have taken place well beyond the margins of the present Connecticut Valley and have since been almost wholly removed by erosion. A remnant of the strata probably of such origin has actually been found 15 miles west of the Connecticut Valley in Connecticut. One might picture this downwarping of the basin to have slowly continued for thousands of feet, during which time the great pile of Triassic strata fully $1\frac{1}{2}$ to 2 miles thick accumulated in it. There are, however, two difficulties in the way of accepting this view. First, the great thickness of such very coarse fragmental material of local origin, especially along the margins of the basin, means that the sides of the basin must have persisted as high very steep slopes during the whole time of the deposition of those coarse materials else the streams could not have transported them. This is particularly true on the eastern side where the very coarse Mount Toby conglomerate is piled against the valley wall for miles. Second, such very steep valley sides could hardly have resulted from simple downwarping of the earth's crust.

An alternative explanation of the mode of sinking of the basin, which has much in its favor, is that, after the downbending had made considerable progress and sediments were accumulating on the floor of the sinking basin, great nearly vertical fractures (faults) developed on each side of what is now the Connecticut Valley proper, and the large earth-block between the faults slowly but intermittently subsided. The Jordan Valley of Palestine is a fine example of a deep narrow valley which has thus been formed by the settling of a long narrow block of the earth between two nearly vertical faults where the sinking has taken place so rapidly in recent geologic time that sediments carried into it have fallen far short of filling it. Fault valleys also occur in southern California and the Great Basin region of Nevada and Utah. Such a fault valley did not result from a single, sudden, grand subsidence of an earth-block. Neither did such a block settle very slowly without interruptions. Much evidence

based upon the study of earth-block movements which have taken place in recent years makes it clear that the development of a great fault trough valley is the result of many sudden successive slippings of the crust along the fault fractures. A single sudden shift of 10 to 40 feet is large.

That the Connecticut Valley district of Massachusetts represents a great sunken fault-block is practically certain, though it should be mentioned that the present depth and relief of the valley are products of erosion since Triassic time rather than direct results of the settling of the fault-block. The faults which bound the great sunken earth block (see map figure 10) follow more or less closely the margins of the present valley or, in other words, the contacts between the Triassic strata and the crystalline Paleozoic rocks. The existence of the faults is proved by the manner in which only moderately tilted Triassic strata rest sharply against the bases of high very steep hills on each side of the present valley as fairly well shown by structure section (figure 9). Since Triassic time the relatively much weaker strata of that age have been cut down by erosion notably below the level of the more resistant Paleozoic rocks, and the nearly vertical fault faces have, above the existing surface of the Triassic strata, been gradually subdued and made less steep by weathering and erosion. During late Triassic time the high steep margins of the sinking basin, which we have shown must have been persistently present in order to permit streams to sweep so much coarse material into the basin, were kept steep and high not only by many repeated sudden downward movements of the earth-block or parts of it, but also very probably by simultaneous rejuvenation or uplift of the land on either side. Because of the almost universally present thick mantle of Glacial and Postglacial deposits in the Connecticut Valley the surfaces of the great marginal faults are nearly everywhere concealed. The city quarry a little north of Northampton lies just west of the western marginal fault, and the granite rock is there traversed by several minor parallel faults which are in turn parallel to the concealed main fault. These minor faults merely represent small dislocations in the near by granite during the great process of faulting. Along these faults in the city quarry the rock is seen to be badly crushed and weathered brown, and some of the fractures contain crystalline calcite which was brought in by underground waters.

How the Triassic Strata were Deposited. A study of the character of the materials which make up the Triassic strata, combined with a knowledge of the topography of late Triassic time, afford us fairly

conclusive evidence as to the conditions under which the strata were deposited. These conditions were apparently much like those which now obtain in parts of Spain and southern California where extensive accumulations of sediments very similar to those of the Connecticut Valley Triassic are taking place. Studies in these and many other parts of the world have made it clear that very thick and widespread bodies of sand, gravel, and mud may accumulate in sinking basins as delta and flood-plain deposits by rivers and in more or less shifting or intermittent lakes. It is, therefore, not necessary to assume that strata like those of Triassic age in the Connecticut Valley were piled layer upon layer under a permanent body of water. It was once held that a narrow arm of the sea in the form of an estuary occupied the sinking basin during late Triassic time, and that, during the ebbing tides, the marks of subaërial exposure, such as ripple-marks, mud-cracks, and tracks of land animals, were formed. This hypothesis also accounted for the absence of marine fossils in the rocks. Professor Barrell, who made a careful study of the conditions under which strata of the kind here considered were formed, has admirably summarized his views regarding the Triassic of the Connecticut Valley in the following words. "The presence of these (subaërial) marks in most parts of the formation, and not exclusively near the margins of the area, shows rather that the water bodies were migrating rivers or shifting lakes, and that the sediments of river flood-plains of great breadth were subjected to periodical drying (in a semiarid climate). The Triassic sediments are, therefore, best regarded as mainly river (and lake) deposits of an inland basin, and, if the sea ever gained access during this period, the evidence of it has not as yet been developed". It should be added that in regions of semiarid climates where precipitation is below normal, there is a strong tendency for most of the water to fall in relatively few seasonal downpours, causing floods. Such intermittent flooding of the Triassic basin of Massachusetts no doubt occurred, and this helps us to understand the origin of the remarkable deposits of that age.

Fossils in the Triassic Strata. Remains or traces of animals or plants preserved in the rocks are called fossils. Although definitely determinable fossils are rare from the Triassic strata of Massachusetts, nevertheless enough have been found to classify them as of late Triassic age. The plant life of that age, millions of years ago, was strikingly different from that of today. Typical flowering plants like those which abound at present, were not yet evolved on the face of the earth. Primitive conifers ("pines"), cycads (socalled

“sago palms”), ferns, and equisetæ (socalled “horsetail plants”) were then the dominant higher types. It is a striking fact that nearly all of the relatively few known fossil plants from the Triassic strata of Connecticut and Massachusetts are from the black (Chicopee) shales which were probably deposited in lakes or swamps where conditions for preservation of the vegetable materials were the most favorable. Among the few localities from which fossil plants, mainly fragments and impressions of conifers, have been found are north of Sunderland, near Montague, Gill, Deerfield, and Greenfield. Several years ago the writer collected some fine specimens of fossil plants, probably stems of conifers, from the Chicopee shale at Holyoke. These wonderfully preserved stems have been altered to a black coaly substance. Fossil ferns have been recorded from the coarse sandy conglomerate on the west side of Mount Tom, the gray sandstone on the west side of Mount Holyoke, and the shales at Gill. For a number of years the writer has shown his classes some very interesting fossil imprints and remains of many sticks of wood on a wide surface of the Longmeadow sandstone by the river east of Mountain Park. These sticks of wood from 1 to 3 feet in length were buried under other layers of mud and sand, and then changed to coal. Erosion has since uncovered this particular stratum, and the impressions of the sticks and even some of the coaly matter are plainly visible.

In regard to the fossil animals Professor Lull says that “the record of animal life is of twofold character; on the one hand, there are the relatively rare actual fossils (remains), and on the other the trails, impressions, and footprints, which occur in these rocks in a profusion and perfection of detail elsewhere unknown. This evidence points to a diverse horde of creatures, both invertebrate and vertebrate. Of the vertebrates there are known with fair assurance worms, mollusks, and arthropods, including insects, and probably crustaceans and myriapods. Of the vertebrates there were doubtless present three classes—fishes, amphibians, and reptiles”. Fresh-water mussel shells (mollusk) impressions have been found near Wilbraham; crustaceans, representing the arthropods, have been collected near West Holyoke; and primitive insects, also representing the arthropods, occur in great abundance in the shales near Turners Falls.

Turning our attention to the fossil fishes, we find that all of them in the Triassic of Massachusetts occur in the Chicopee shale which also contains most of the fossil plants. Numerous fishes,

representing several species in excellent state of preservation, have been obtained at Turner's Falls; north of Sunderland (Whittemore's Ferry); South Hadley Falls; and Chicopee, especially at the first two places named. The prevailing types of fishes of today did not exist during Triassic time. In fact they were not evolved until the next (Jurassic) period. The fossil fishes of the Connecticut Valley represent lower forms, known as ganoids, which are relatively rare today, an example being the gar-pike.



FIG. 13. RESTORATION OF THE SKELETON OF ONE OF THE TWO-LEGGED DINOSAURIAN REPTILES ABOUT SEVEN FEET LONG WHICH ROAMED THE SITE OF THE CONNECTICUT VALLEY MILLIONS OF YEARS AGO IN TRIASSIC TIME. THIS TYPE OF CREATURE HAS LEFT FOOTPRINTS IN THE STRATA (SEE FIGURE 14). AFTER MARSH.

We shall now direct attention to the most wonderful fossil records of the life of the Triassic period in Massachusetts. We refer to both the actual bones and the footprints of the pioneers of one of the most remarkable groups of animals which ever inhabited the earth. These were the land reptiles called dinosaurs which began in the late Triassic period, reached their climax in both size and diversity of forms in the Jurassic and Cretaceous periods, after which

they completely vanished from the earth. Some of them, which grew to be nearly 100 feet long, walked on four legs. Two-legged forms only, and of much smaller size, are known to have lived in central western Massachusetts during late Triassic days. A good idea of the general structure of these remarkable creatures which trod the earth so long ago may be gained from figure 13 which is a restoration of a common form of moderate size based upon actual fossil bones of an almost perfect skeleton found in Connecticut. This two-legged dinosaurian reptile grew to be nearly 8 feet long, and it has left tracks nearly 6 inches long in the sandstone. Judging by the sharp teeth and strong grasping claws on the arms, he was a very active carnivorous reptile which preyed upon the smaller vertebrate animals of his time. Reptilian bones have been found at 11 localities throughout the Connecticut Valley. These bones represent 8 dinosaurs, including 5 species, and 3 other reptiles. In Massachusetts the localities are near Greenfield, Belchertown, South Hadley, Springfield, and Longmeadow. A fine skeleton was found in a slab of loose sandstone near South Hadley by Professor Talbot of Mount Holyoke College. This represented an unusually small two-legged dinosaur less than 4 feet long. Unfortunately the specimen was ruined by fire several years ago. From our knowledge of the actual bones and the great number and variety of footprints we can be sure that dozens of species of dinosaurs roamed the floor of the great sinking basin of central western Massachusetts in late Triassic time. Some were flesh-eaters and others plant-eaters. They ranged in size from less than 4 feet to fully 30 feet. The very largest were great two-legged flesh-eaters. A few species of other types of reptiles also existed, some of which were four-legged. Practically all of the dinosaur remains and footprints occur in various layers throughout the upper half of the Triassic strata. Allowing for a reasonable amount of time for the accumulation of the thousands of feet in thickness of these strata, it is certain that the dinosaurs inhabited the region for at least hundreds of thousands of years.

In marked contrast to the relative scarcity of actual fossil bones is the great wealth of footprints of dinosaurs so perfectly preserved in the shaly sandstone of the Longmeadow formation. Thousands of specimens have been found throughout the Connecticut Valley of both states, and these represent only a fraction of the actual number of tracks which were left to be sealed in the earth's crust. A great many have been carried away by deep erosion of the rocks since Triassic days. Great numbers are still buried within the strata

or are covered by soil or Glacial and Postglacial materials. Only those which happened to be at or very close to the surface have been seen or removed by digging. Thousands of the footprints have been removed and placed in the geological collections at Amherst and Yale, and many have gone into scientific collections in all parts of the world. The largest numbers by far have been found at various localities in the general vicinities of Turner's Falls and South Hadley. In regard to the perfect preservation of such a vast number of geologically ancient animal tracks no district in the world is at all comparable to the Connecticut Valley. Long ago President Hitchcock of Amherst carefully studied and published elaborate accounts of the footprints. His first article appeared in 1836. He described tracks from 38 localities scattered throughout the Connecticut Valley. The people of the valley commonly refer to these footprints as "bird-tracks" because Hitchcock so first described them and, in view of their shape and the lack of actual skeletons, this was then a very reasonable conclusion. The earliest known bird, however, lived during a later (Jurassic) period of geological time.



FIG. 14. FOOTPRINTS OF A SMALL DINOSAUR ON A SLAB OF TRIASSIC SANDSTONE FROM THE CONNECTICUT VALLEY. LENGTH OF EACH TRACK, ABOUT FOUR INCHES. SPECIMEN AT SMITH COLLEGE. PHOTOGRAPHED BY THE AUTHOR.

What are these footprints like? How were they preserved in the rocks? What history do they record? We can perhaps best answer these questions by confining our attention to a single outcrop of the sandstone on which many tracks may now be seen. Best of all, and,

so far as known to the writer, the finest of its kind on earth, is a ledge about 150x30 feet between the main road and the railroad three-fourths of a mile east of Mountain Park, or about half way between Smiths Ferry and Holyoke. Each year the writer conducts classes in geology to this wonderful ledge which he calls the "dinosaur ledge" because of the marvelous display of dinosaur tracks which it contains. It is truly a full-page illustration in nature's great earth-book. The rock is a shaly sandstone which was deposited under water as a muddy fine sand in thin layers. The layers (strata) now show a strong tilt toward the east, but when they were deposited they were of course horizontal or nearly so. Dozens of tracks made by several sizes and species of dinosaurs are in an amazingly perfect state of preservation on the surface of the ledge. The tracks are literal "footprints in the sands of time", the time when they were made having been no less than 8 or 10 million years ago! Tracks of certain shape and size are generally serially arranged, that is they mark exact spots step after step where individual dinosaurs trod across the original surface. In one case the writer is able to step, with a stride of about $3\frac{1}{2}$ feet, in a series of 11 footprints, each about a foot long, exactly where a great dinosaur left his foot print impressions on the original surface. All or nearly all of the tracks are three-toed. They range in length from 3 or 4 inches to 15 or 16 inches. The larger tracks are sunk below the general surface from one-half of an inch to two inches. All of the tracks were made when the rock material was fairly soft in the condition of a sandy mud flat soon after the waters receded from it. Ripple-marks left by the retreating gently agitated water are perfectly preserved on parts of the surface. In one place we can see where a large dinosaur stepped on the soft ripple-marked surface and bent the layers down. At another place we can see where a small fellow, whose footprint is only a few inches long, dragged his tail in the mud. A slab of rock in the Amherst Museum much better illustrates a similar thing. During the exposure of this soft layer a very brief shower passed over the district as proved by the impressions of large raindrops very clearly preserved on the ledge!

A brief summary of the history of the "dinosaur ledge" may be stated as follows. During the piling up of the sediments on the floor of the great sinking basin in central western Massachusetts in late Triassic time at least 8 million years ago, water (probably flood water) covered the site of the ledge and a layer of sandy mud was deposited in it. Agitation of the water during its recession caused the ripple-marks. After the retreat of the flood water the surface of

the sandy mud was exposed to the air in a more or less soft condition for a time. Various dinosaurs, some of them two-legged flesh-eaters fully 25 feet long, tramped over the surface sinking their feet into the soft material. Then, due to exposure to the sun, the mud became hardened. Sometime later another flood, carrying more sandy mud, swept over the surface and the tracks and ripple-marks were buried. Hundreds, and perhaps thousands, of feet in thickness of other layers continued to pile over the tracked surface during Triassic time, and so the footprints became sealed in the earth. Then, as a result of an earth-crust disturbance, the strata were tilted toward the east. Finally, after long ages of wearing away (erosion) of the overlying strata, the old tracked surface has again been exposed as we see it today.

Volcanic Activity (Outpourings of Molten Rocks). In the discussion of the late Triassic history of the Connecticut Valley region mention of the interesting and important volcanic activity of the time has thus far been purposely omitted. This has seemed best in order to avoid confusion in the attempt to give the reader an understanding of the conditions under which the remarkable strata of the region were formed. The volcanic rocks (lavas, etc.) are of exceptional interest not only because of their manner of origin, but also because of their resistance to erosion which accounts for the fact that they now stand out so boldly above the general valley floor as ridges like the Mount Tom and Mount Holyoke ranges and the Deerfield ridge.

After the Triassic sediments had piled up to a thickness of thousands of feet, a fissure many miles long opened in the bottom of the great sinking Triassic basin and through it a vast flood of molten lava was poured out upon the surface. The exact location of the fissure is not known, but it was probably not far from the present outcropping belt of lava (see map figure 10). The lava sheet was thickest toward the middle of this belt, an actual thickness of over 300 feet now being exposed in Mount Tom. From each side of the fissure the liquid rock spread or flowed over the surface forming a layer at least several miles wide where it was thickest. At or about the same time a smaller scale outpouring of lava took place in the northern part of the basin in the vicinity of Greenfield and Deerfield. Geologic map figure 10 shows the present surface extent of this lava of the Deerfield Ridge. "The mass is made up of a superficial sheet and two intermediate sheets full of steam holes, indicating three immediately successive flows."—Emerson.



FIG. 15. THE STEEP WESTERN FACE OF THE MOUNT TOM RANGE AS VIEWED FROM NEAR EAST-HAMPTON. THE CLIFFS CONSIST OF COLUMNAR LAVA OF TRIASSIC AGE RESTING UPON SANDY CONGLOMERATE. PHOTOGRAPHED BY THE AUTHOR.

What are some of the proofs that these rocks are really lavas which poured out on the earth's surface? First, the rock is in composition, texture, and lack of stratification exactly like certain modern lavas definitely known to have flowed out in molten condition. Second, the strata on which they rest show distinct effects of high temperature, that is just under the contacts the strata have been baked and usually changed in color from red to gray as is excellently shown in the big quarries east of Westfield, and also on the west side of Mount Holyoke. Third, they locally contain small baked fragments (inclusions) of the stratified materials, as for example, in the railroad cut near the south end of Ashley Pond west of Holyoke. Fourth, the distinctly porous character of the upper surfaces of the sheets of rock was caused by the escape of steam from the upper parts of the molten floods, this being a phenomenon very characteristic of cooling surfaces of modern lava flows. Such steam holes are finely exhibited in the electric railroad cut near the foot of the Mount Tom railway, and also in the lava east of Sunderland.

From the above discussion it is evident that the statement sometimes made that Mount Tom is an old volcano is not true.

The whole upper part of the mountain does consist of lava, but the mountain as it exists today represents merely the edge of the tilted and eroded sheet of lava (see figure 19). In no sense of the word is the mountain really an old volcano.

A very interesting feature of the Mount Tom—Mount Holyoke lava sheet is its more or less well developed columnar or "palisade" structure caused by cracking of the rock into columns as a result of its cooling and contraction from the molten condition. Titan's Piazza furnishes the finest exhibition of this structure where, in the western face of the mountain between Mount Holyoke and the river, great five or six sided columns several feet thick form a long cliff 30 to 50 feet high (see figure 16). Locally the underlying sandstone has been worn (eroded) away in such a manner as to cause one or two of the rows of columns to overhang forming a sort of rock shelter. Less perfectly developed columnar structures are exhibited in many other places as at Titan's Pier by the river opposite Mount Tom Junction; on the western side of the top of Mount Nonotuck; in the Notch south of Amherst; and on the west face of Mount Tom.

After the outpouring of the two sheets of lava above described, the interrupted deposition of sediments again proceeded and stratified materials were laid down on top of the lavas soon completely burying the two great horizontal flows. In the Deerfield-Greenfield region no other volcanic activity took place, but from near Mount Holyoke eastward and southward, after the great lava sheet was buried under sediments to a depth of a few hundred feet, there was another volcanic outbreak. A second but smaller lava outpouring took place, its maximum thickness apparently having been not more than 100 feet. This lava is well exposed with some interruptions as a narrow belt a little to the east and south of the main (older) belt of lava as shown on the geologic map (figure 10). It is especially well exhibited on the ridge which lies between the Mount Tom Range and the river. At a number of places east and southeast of Mountain Park the highly porous character of part of this lava flow is well shown.

Immediately following the second outflow of lava, explosive volcanic activity took place on a considerable scale. Along the general line of outcrop of the second lava there existed a number of small but very active volcanoes. This is clearly proved by the fragments of volcanic rock which were blown into the air and spread over the country for a mile or more from the volcanic centers. This fragmental volcanic material now makes up a good portion of a



FIG. 16. DETAILED VIEW OF THE GREAT COLUMNS OF LAVA AT "TITAN'S PLAZZA" ON THE WESTERN FACE OF MOUNT HOLYOKE. THE COLUMNS RESULTED FROM CONTRACTION OF THE LAVA DURING ITS SOLIDIFICATION FROM A MOLTEN CONDITION MILLIONS OF YEARS AGO DURING TRIASSIC TIME. THE ENDS OF THE OVERHANGING COLUMNS SHOW REMARKABLE EFFECTS OF WEATHERING OR DISINTEGRATION. PHOTOGRAPHED BY W. E. CORBIN OF FLORENCE.

formation which directly overlies the second lava to the south and east of the Mount Tom and Mount Holyoke Ranges. This formation, which Emerson has named the "Granby tuff", is very variable in composition. Its thickness is seldom if ever more than 100 feet. Excellent exposures may be seen along the road from 1 mile north to 2 miles south of Smiths Ferry (see figure 17). Many angular fragments of lava varying in size from dust particles to blocks a foot across occur in the formation. These are usually directly associated with sandstone material. In some parts of the formation the volcanic fragments predominate, and in others the sandstone. Obviously, in many cases showers of fragments blown out of the volcanoes fell upon, and more or less mixed with, the muddy sands which were accumulating on the floor of the sinking Triassic basin. "The great angular blocks of diabase (lava) a mile north of Smith Ferry, by the cemetery, can be seen to have fallen into the mud, now turned to sandstone, and to have bent down the layers."—Emerson. In other cases moving water appears to have caused some of the showered volcanic fragments to become mixed with the mud and sand.

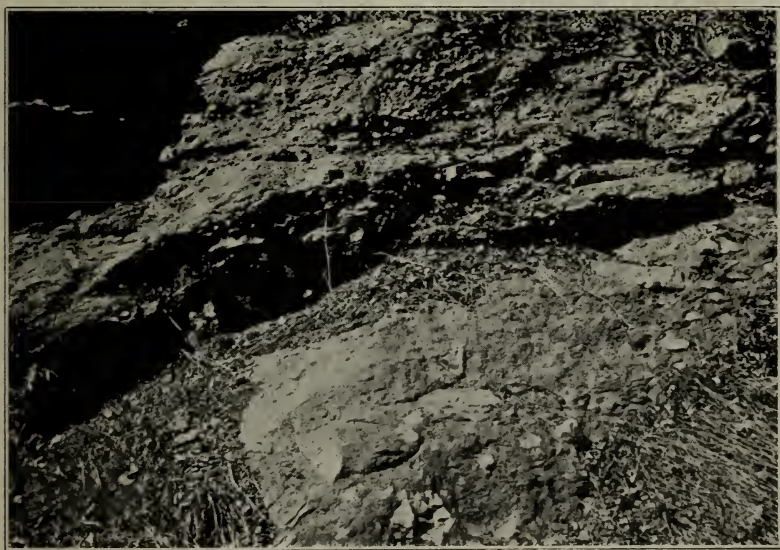


FIG. 17. A LEDGE OF THE SO-CALLED GRANBY TUFF FORMATION WHICH CONSISTS OF MORE OR LESS ANGULAR FRAGMENTS OF VOLCANIC ROCK (LAVA) MIXED WITH SANDSTONE MATERIAL BY THE STATE ROAD ONE MILE NORTH OF SMITHS FERRY. THE LAVA FRAGMENTS, MANY OF WHICH SHOW IN THE PICTURE, WERE HURLED OUT OF SMALL EXPLOSIVELY ACTIVE VOLCANOES DURING TRIASSIC TIME PHOTOGRAPHED BY THE AUTHOR.

The steep hill known as Little Mountain near Mountain Park is of unique interest because there is strong evidence that it represents the core of one of the active volcanoes of the late Triassic time under discussion. Little Mountain is plainly a plug of lava almost completely surrounded by sandstone. This lava clearly shows tongues or offshoots which were, in molten condition, forced into the adjacent sandstone. This lava plug quite certainly represents the neck or feeding channel of an old volcano the crater of which lay well above the present level of the hill top and has long since been removed by erosion (see figure 19). Even in this case the present hill (Little Mountain) is, strictly speaking, not an extinct volcano, but it is the core or erosion remnant of a volcano which was active millions of years ago. During explosive eruptions fragmental lava materials, now seen in the Granby tuff formation along the main road one-half of a mile to the east, were no doubt hurled out of that particular volcano.

JURASSIC AND CRETACEOUS HISTORY

Fault Block Mountains of the Jurassic Period

After the long and very eventful late Triassic history of the Connecticut Valley region, the next important thing that happened was the development of a great series of fault fractures during Jurassic time causing the whole district to be broken up into earth blocks which slipped past each other. During the process of faulting and slipping the earth blocks nearly all became distinctly tilted, most of them 5 to 20 degrees to the east and southeast as shown by the structure sections in figures 9 and 19. On the geologic map (figure 10) only those larger faults are indicated which have been more or less definitely located in the field. Without question many others exist but they are more or less effectually concealed under the Glacial and Postglacial deposits. The actual amount of nearly vertical slipping along these larger faults was commonly from 100 to 1000 feet or more. In addition to these there are numerous smaller faults whose displacements are to be measured by only a few feet or tens of feet, excellent examples occurring in the ledges between Mountain Park and the base of the Mount Tom railway (see figure 18), and in the eastern half of the Holyoke Range.

The reader should not infer that the powerful crustal disturbance which caused the fracturing (faulting) of the crust, and resultant tilting of the earth blocks, took place suddenly as a single great



FIG. 18 A SMALL FAULT IN THE TRIASSIC SANDSTONE AND SHALE FORMATION NEAR MOUNTAIN PARK. THE AMOUNT OF DISLOCATION AS INDICATED BY THE BROAD WHITE LAYER IS SHOWN TO BE ABOUT TWO AND ONE-HALF FEET. THIS ILLUSTRATES THE PRINCIPAL OF THE GREAT TILTED FAULT BLOCKS OF THE CONNECTICUT VALLEY (SEE FIGURE 19). PHOTOGRAPHED BY THE AUTHOR.

operation. For the development of the larger faults a considerable amount of time was necessary during which repeated sudden movements (slippings) occurred. From the study of sudden earth shiftings along faults during the last 100 years we know that such movements seldom amount to more than a few feet or tens of feet. Each movement of the kind causes an earthquake. In early Jurassic time, then, when the earth blocks were being tilted by repeated sudden slippings, the Connecticut Valley district was subject to many violent earthquakes. Movements also more than likely occurred at the same time along the great faults which bound the valley on each side.

An important effect of the faulting and tilting of the earth blocks was to break the nearly level floor of the deeply filled Triassic basin into many more or less parallel ridges, the edge of each tilted block having formed a ridge. Some of the ridges probably rose to moderately mountainous heights, though it must be remembered that the wearing down process of erosion was constantly at work even while the tilting of the blocks was taking place. In any case we can be

reasonably sure that, as a direct result of the Jurassic faulting, the site of the Connecticut Valley was then notably more rugged than it is today, the whole area having been occupied by various ridges and even moderately high ranges.

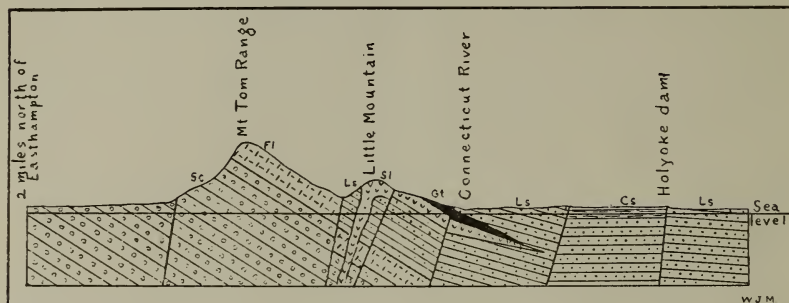


FIG. 19. DETAILED STRUCTURE SECTION SHOWING THE ARRANGEMENT OF THE ROCKS AS THEY WOULD APPEAR ON THE FACE OF A VERTICAL SLICE THROUGH THE EARTH'S CRUST FROM A POINT TWO MILES NORTH OF EASTHAMPTON THROUGH THE GREAT DAM AT HOLYOKE. VERTICAL SCALE MUCH EXAGGERATED. THE ROCKS ARE OF TRIASSIC AGE. SC: SUGARLOAF CONGLOMERATE; FL: FIRST LAVA FLOW; LS: LONGMEADOW SANDSTONE; SL: SECOND LAVA FLOW; GT: GRANBY TUFF; CS: CHICOPEE SHALE. DRAWN BY THE AUTHOR

By this time the reader may be wondering how we know that the faulting took place during the Jurassic period. In the first place, all the Triassic strata, even including the latest, were involved in and affected by the faulting, thus proving that the disturbance took place after they were deposited, that is after Triassic time. In the second place, the tilting of the fault blocks must have been completed during Jurassic time because, already well before the close of the Mesozoic era (as shown below), the whole region had been so planed down by erosion that all of the fault block mountains had disappeared as topographic features, so that at least a period of geologic time must be allowed for the accomplishment of so much work of erosion. In the third place, it is at least strongly suggestive that the process of accumulation of strata in the great sinking basin was brought to a close by the crustal disturbance of faulting. If so, the tilting of the fault blocks must have begun very early in the Jurassic period.

Great Erosion Interval of Later Mesozoic Time

It has long been known that most of the eastern United States where the higher lands such as New England, New York, and the Appalachians are now situated was, during later Mesozoic time, subjected to such widespread and deep erosion that it was all worn

down to the condition of a remarkably smooth plain near sea level with slow moving streams wandering over its surface. Such a surface produced by erosion is called a "peneplain". In reference to this great area Professor Berkey has well said: "The continent stood much lower than now. Portions that are now mountain tops and the crests of ridges were then constituent parts of the rock floor of the peneplain not much above sea level. . . . The ridges and valleys, the hills, mountains, and gorges of the present were not in existence, except potentially in the hidden differences of hardness or rock structure". Over southern New England occasional hills or knobs of harder or more favorably situated rock masses still rose above the general level of the vast otherwise monotonous surface of the peneplain. Mounts Greylock, Wachusett, and Monadnock mark the sites of such residual hills or remnants of erosion which rose above the peneplain surface, though of course they were then much lower than now.

It would carry us too far afield to go into the various proofs for the existence of the vast peneplain over all of southern New England during late Mesozoic time. One important line of evidence may, however, be briefly mentioned, namely, the "even sky-line" which is such a striking feature of the landscape. If, for instance, one looks out over the country from the summit of Mount Tom on a very clear day he is quickly impressed by the fact that all but very few of the myriads of higher summits rise to very nearly the same altitude. Far off in the distance he may get glimpses of Greylock, Monadnock, and Wachusett rising above the general level. Since rocks of all kinds and many ages are, with very few exceptions, all truncated or planed off to this one general level as indicated by the "even sky-line", it is impossible to account for such a surface except as an upraised and subsequently partly eroded peneplain. Although the eye cannot detect it, this "even sky-line" actually slopes gradually downward toward the south-east in central and western Massachusetts and Connecticut. Standing on the summit of Mount Tom one can easily imagine the whole Connecticut Valley and its tributary valleys in the highlands on either side to be filled up to the level of the sky-line. This would essentially restore the upraised peneplain surface.

A few years ago Professor Barrell advanced the theory, not yet generally accepted, that the great peneplain was not wholly the work of weathering and stream erosion, but that, during portions of the Cretaceous and Tertiary periods, the sea actually overspread

all of Connecticut and most of Massachusetts, and accomplished considerable work of erosion during its advance and retreat across the previously fairly well developed peneplain surface. The highland surface of southwestern New England does not, according to Barrell, "consist of one irregular sloping plain, with low hills rising above and deep valleys cut below. On the contrary, if the valleys be filled in imagination and the ravages of erosion repaired until the country is level with the higher hill tops, it will be found that the upland level resembles an irregular flight of giant stairs. The rises are commonly about 200 feet in height, but weathered to very gentle slopes. The treads average from five to ten miles in breadth and are more nearly level than is the general slope of the upland surface. . . . The interpretation of the stair-like or terrace character of the restored highland surface seems to demand is, that, after a peneplain had been developed, the sea planed inland along the entire Atlantic shore, completely across the state of Connecticut and most of Massachusetts. During this invasion the sea may have partly cut the benches, but most of the terraces were doubtless cut as sea cliffs during oscillations of the shore which accompanied emergence of the land".

If, after much careful field work on the problem is carried out, Barrell's theory is proved to be correct, it would mean simply that the vast peneplain was produced by a combination of stream and sea erosion. In any case, the evidence for the existence of a real peneplain over southern New England in late Mesozoic, to possibly very early Cenozoic time, is clear and conclusive.

CENOZOIC HISTORY

The Tertiary Period (Origin of the Principal Existing Relief Features)

Only a few million years ago, in the early part of the present (Mesozoic) era of geologic time, there was no Connecticut Valley with the Mount Tom Range, Mount Holyoke Range, the Sugarloaf Mountains, the Deerfield Ridge, and Mount Toby rising boldly above its floor as today. Neither did the hills and valleys of the highlands on either side of the valley then exist. As already pointed out, the whole area of central western Massachusetts was then a great slowly rising peneplain surface. The rising surface was locally somewhat warped, but a general slope to the southeast was a direct effect of the uplift. The uplift of the peneplain was an event of prime importance because all of the major existing relief features of southern

New England have been sculptured out of that upraised surface mainly by stream erosion. The uplift of a thousand feet or more in central western Massachusetts caused a great revival of activity of streams which became very vigorous agents of erosion. Since the uplift of the southern New England peneplain was differential, that is in general greater towards the north, the main streams took southward courses. This then clearly explains why southern New England slopes to the south, and why the principal streams, like the Connecticut and Housatonic Rivers, flow southward.

The larger original streams which flowed down the initial slope of the upraised and tilted peneplain first cut channels into the widespread superficial alluvial and soil deposits which had accumulated on the plain, and then into the underlying bed rock. Their courses were, therefore, established in the superficial deposits and, when the underlying rocks were reached, the same courses had to be followed entirely without reference to the nature and structure of those underlying rocks. A wonderful illustration of this principle is where the Connecticut River has cut a great notch or gap through the Mount Tom-Holyoke Range. In no sense of the word did the river flow against the range and cut its way through, but rather its course was determined across this district on the surface of the upraised peneplain at a level fully a thousand feet higher than the present river level long before the existing mountain range appeared as a topographic feature. The course of the young, and for a long time swift, river having been established upon the upraised peneplain surface between Northampton and Holyoke, it has had to maintain essentially the same direction cutting through hard rock (lava) and weaker rock (conglomerate and sandstone) alike.

While the great master stream—the Connecticut—was sinking its valley into relatively weak and resistant rocks alike, side streams or tributaries came into existence. Some of the larger older tributaries like Westfield, Deerfield, Miller's, and Chicopee Rivers, may have had their courses inaugurated on slopes of the warped upraised peneplain which would account for the fact that these streams cut across belts of rocks of varying kinds instead of sinking valleys very largely in softer rocks parallel to those belts. The tributaries have gradually increased in number until now a great many exist forming a network drainage in central western Massachusetts, this drainage all passing into the Connecticut. The larger streams have steadily increased in size at the expense of the smaller ones. This is because

they have been able to cut down their valleys faster with resultant diversion of more and more drainage into them.

We can now readily understand how the major existing relief features of central western Massachusetts have been produced since early in the Cenozoic era or very late in the Mesozoic era as a direct result of the dissection by stream erosion of the upraised and more or less warped great peneplain which covered the whole region geologically recently, that is only a few million years ago. The Connecticut Valley proper is so much lower, and in general more level, than the high rugged hilly country on either side because the largest stream (the Connecticut) of the region there follows the wide belt of relatively weak Triassic strata (see geological map figure 10). The large Connecticut and its tributaries have been able to cut down (erode) these Triassic stratified rocks much faster toward sea level than the smaller tributaries in the highlands on either side have been able to lower the general level of the much more resistant crystalline very ancient rocks there. In fact, as already intimated, the general level of the highlands forms the "even sky-line" of the old upraised peneplain surface which has as yet been only locally incised by the streams.

Why do the Mount Tom-Holyoke Range, Mount Toby, and the Deerfield Range stand out in such bold relief above the generally wide nearly flat floor of the Connecticut Valley? Simply because these high masses consist of rocks which are much more resistant to erosion than the surrounding Triassic strata. Because of the unusual resistance of the lavas of the Mount Tom—Holyoke Range and the Deerfield ridge, and the tough very coarse conglomerate of Mount Toby, these mountains have literally been sculptured or carved out in bold relief by the wearing down of the much weaker rocks around them. Because of the strong tendency of the sandstone to be removed from under the thick tilted lava sheet the Mount Tom-Holyoke Range presents a very steep western and northern front, this being well illustrated by figures 3 and 15. The Sugarloaf Mountains are also erosion remnants, Little Sugarloaf rising towerlike for hundreds of feet as an especially striking feature of the landscape. It is quite certain that the lava sheet near Sunderland (see map) formerly extended farther west over the sites of the two mountains protecting the underlying sandy conglomerate as it does now in the Deerfield Range. During the process of erosion above described, caps of the hard lava were for a time left on the two Sugarloaf Mountains and thus the sandy conglomerate strata were pro-

tected against erosion. Finally, in very recent geological time (possibly during the Ice Age) the lava caps were eroded away, and the mountains are now crumbling down.



FIG. 20. SOUTH SUGARLOAF MOUNTAIN AS SEEN FROM NEAR ITS SOUTHERN BASE
CHAS. H. HOWARD, PHOTOGRAPHER, NORTHAMPTON

By late Tertiary time or, in other words, a little before the opening of the great Ice Age of the present (Quaternary) period, the Connecticut River, because of its size and favorable situation in a belt of weak rocks, had cut down its valley so close to sea level that it reached "grade", that is a condition in which, because of low velocity, it could no longer saw down its channel. As usual in such a stage of river history, the Connecticut then meandered back and forth from one side of its valley to the other in the form of sweeping curves. The side cutting due to the meandering of the river greatly aided in the development of the broad valley floor on the Triassic strata, while the hard lavas stood out boldly against the lateral planation process. This broad valley floor was really a local peneplain (see figure 21).

That the country was essentially in the condition above described just before the Ice Age is clearly proved by the fact that Glacial and Postglacial deposits are not only very widespread as a mantle over the floor of the Connecticut Valley today, but also in nearly all the valleys of the highlands on each side. The evidence

is overwhelming that the vast glacier of the Ice Age did not carve out the main existing relief features of the region. To be sure the ice did some work of scouring but not enough to greatly alter the face of the land. In the very short time since the Ice Age the streams have only fairly started to remove the Glacial and Postglacial deposits from the valleys.



FIG. 21. VIEW NORTHEASTWARD ACROSS THE CONNECTICUT VALLEY FROM A HILL ONE-HALF OF A MILE WEST OF NORTH HATFIELD. THE REMARKABLY FLAT VALLEY FLOOR IS HERE FIVE MILES WIDE SOUTH AND NORTH SUGARLOAF MOUNTAINS IN THE LEFT DISTANCE, AND MOUNT TOBY IN THE RIGHT DISTANCE. PHOTOGRAPHED BY THE AUTHOR.

Before passing to a discussion of the great Ice Age and its effects, another disturbance of the earth's crust must be considered. After the Tertiary erosion had proceeded far enough to dissect the hard crystalline rocks of the upraised peneplain into the hilly country much as it is today, and to cut down the weaker Triassic strata into the broad flat-bottomed valley near sea level, another broad uplift of the region took place. The whole northern Atlantic Coast area was in fact affected by this uplift which occurred not long before the Ice Age and the land then stood notably higher than at present with the seashore considerably farther out. The larger rivers, like the Hudson and Connecticut, were especially revived in activity as recorded by the narrow inner valleys and gorges which they cut into the floors of their wide nearly level valleys. Borings near West Point, New York, have shown this inner valley of the Hudson

to be hundreds of feet deep, and it extends out across the floor of the shallow sea for 100 miles beyond New York City. The Connecticut across Massachusetts also cut a gorge (now below sea level) into the bottom of its broad (graded) valley. These gorges clearly indicate a renewed uplift of the land at least hundreds of feet above the present level because the notable revival of activity of the streams could not otherwise have taken place. The gorge cutting was interrupted by the spreading of the great glacier over the region as proved by the fact that the gorges are now mostly filled by Glacial and Postglacial deposits. A subsidence of the whole region, which took place in the latter part of the Ice Age, has, however, brought the old graded floor of the Connecticut Valley back to near its former (Preglacial) level.

Quaternary History (The Great Ice Age and After)

General Considerations. In the above discussion of the Tertiary history we showed how the major topographic (landscape) features of central western Massachusetts came to be as we see them today, these features being now essentially as they were at the close of Tertiary time or, what is the same, just before Quaternary or Glacial time. We are now ready to consider the salient points in the last important chapter in the history of the region, that is the Quaternary or Glacial and Postglacial history. The Quaternary is the last period of earth history, and it still continues for it has led up to present day conditions. This period was ushered in by the spreading of vast ice sheets over much of northern North America and northern Europe. This event was one of the most interesting and remarkable of geological time. An area of nearly 4,000,000 square miles of North America was covered by ice at the time of maximum glaciation, and the ice very slowly flowed out in all directions from three main centers of accumulation in Canada.

Some of the proofs for the former presence of the great ice sheet are the following: (1) polished and scratched rock surfaces at all altitudes which are precisely like those produced by existing glaciers, and which could not possibly have resulted from any other agency; (2) glacial boulders, called "erratics", which are generally more or less rounded or faceted and often scratched, and which have often been transported many miles from their parent ledges and scattered over all parts of the country, high and low; and (3) deposits, including true moraines (see below) and the very widespread

mantle of heterogeneous glacial débris, which are clearly ice transported materials usually resting by sharp contact on the bed rock.

Depth and Direction of Movement of the Ice. It was the vast glacier whose center of accumulation was in Labrador which spread across New England completely burying the highest summits. Over central western Massachusetts the general movement of the ice was

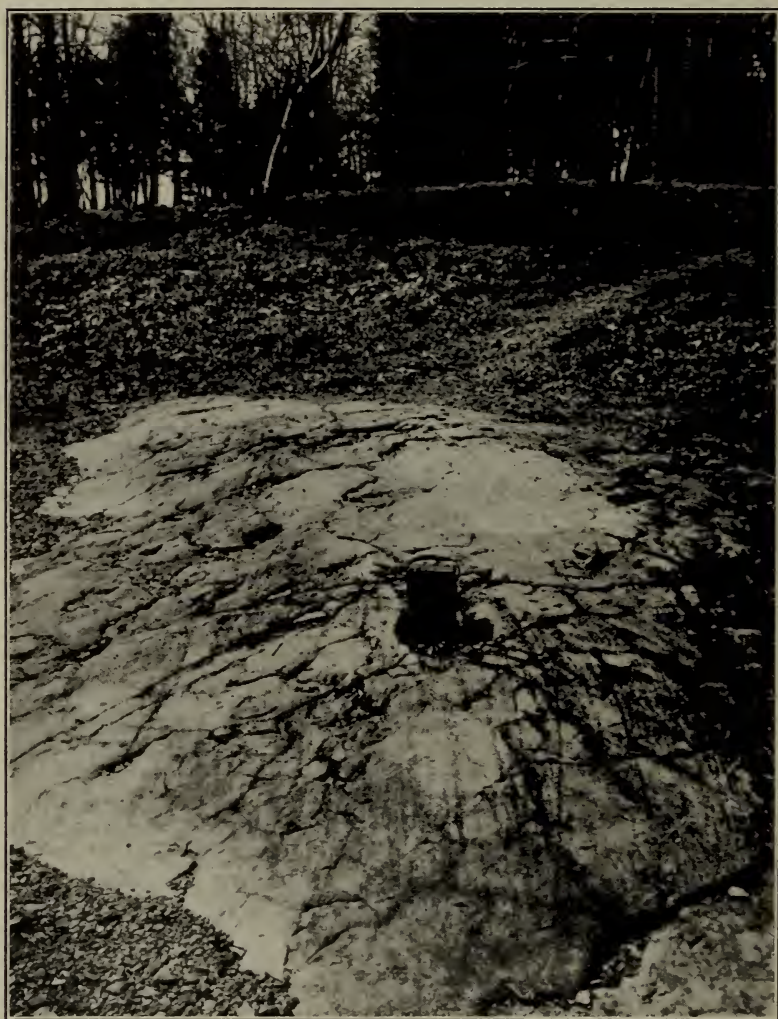


FIG. 22. A SMOOTHED AND SCRATCHED LEDGE OF LAVA—A RECORD LEFT BY THE VAST GLACIER OF THE ICE AGE—AT THE BASE OF THE MOUNT TOM CABLE RAILWAY. PHOTOGRAPHED BY THE AUTHOR.

southeastward with a strong tendency for the current to be deflected more directly southward through the Connecticut Valley proper. How are such facts known? The evidence from the distribution of glacial deposits (including boulders) and the glacial scratches is clear and conclusive. Such phenomena may be observed even on many of the highest points. For example, on top of Mount Tom there are not only many glacial pebbles and small boulders of various rock types entirely different from the rock of the mountain and carried from ledges miles to the north, but also wonderfully well preserved ice scratches and smoothed and even grooved rock ledges. These scratches and grooves point southward. Many of the exposures of lava from the base to the summit of Mount Tom along the cable railway are beautifully polished and scratched (see figure 22). Near the top of Mount Holyoke ledges of lava are finely smoothed with grooves cut into them showing that the ice rode southward over the top of the mountain. On top of both Mount Nonotuck and South Sugarloaf there are less conspicuous glacial marks. Various ledges on the valley floor also show similar marks. On the highlands on either side of the Connecticut Valley many ledges exhibit glacial marks whose general direction is more to the southeast.

Basing our conclusion upon facts like those above stated, we can be sure that the great glacier, as it very slowly flowed across the country toward the south and southeast, gradually increased in thickness until the highest points were completely submerged under the ice. The top of Mount Tom lay at least 1000 feet under the surface of the glacier. The country was then buried under a vast, monotonous, nearly level ice sheet very much like Greenland today. It is well known from studies in the upper Mississippi Valley and Europe that there were several great advances and retreats of the ice during the Ice Age yielding interglacial stages of warmer climate. In southern New England there is not much evidence for more than one or possibly two such ice advances and retreats. Although we do not know how long the Ice Age lasted in years, nevertheless good estimates show its duration to have been probably between 500,000 and 1,000,000 years.

An interesting and instructive comparison of certain physical geography conditions in the history of central western Massachusetts here occurs to the writer. Instead of the present beautiful and very diversified landscape, three kinds of almost perfect plains are definitely known to have existed over the whole region. Many millions of years ago, as we have already learned, sea water covered the

region. This was a great water plain. Late in the Mesozoic era, or very early in the Cenozoic era, only a few million years ago, a vast plain of erosion (peneplain) covered the whole region near sea level. This was a great land plain. During the great Ice Age, only some hundreds of thousands of years ago, a vast nearly perfectly level sheet of ice overspread the region. This was a great ice plain.

Ice Erosion. Glacial ice, like flowing water, has very little erosive effect upon hard rocks unless it is properly supplied with tools. When flowing ice is shod with fragments of hard rocks its power to erode is often appreciable because the work of abrasion is mostly accomplished by the rock fragments rather than by the ice itself. A little search will reveal polished and scratched rock ledges in almost any part of central western Massachusetts. The freshness and hardness of so many rocks surfaces prove that the ice eroded or wore away all of the Preglacial soil and rotten rock, and often some of the fresh rock. During the very long Preglacial time, rock decomposition must have progressed so far that rotten rock, including soils, had accumulated to considerable depths over much of the country as is the case today in the southern states. Such soils are called "residual" because they have been derived by the disintegration or decomposition of the bed rock upon which they rest. One now rarely ever sees rotten rock or residual soil in its original position in Massachusetts because such materials were nearly all scoured off by the passage of the ice, mixed with other soils and ground up rock fragments, or reworked and carried away by water since the Ice Age and deposited elsewhere. Such are called "transported soils" which are abundantly present over the floor of the Connecticut Valley.

One of the finest examples of deeply weathered rock left intact by the ice is by the road near where the electric railway crosses the concrete bridge between Leeds and Haydenville. A mass of granite 25 feet thick is there so badly weathered and decomposed that it is all crumbling away to soil. A layer of Glacial material rests on top of it. The ice, as it moved across the narrow Mill River valley, somehow failed to scour away this rotten rock. Just across the river along the railroad much soft decomposed granite containing large cores of relatively fresh granite are excellently exhibited (see figure 7).

In addition to carrying away most of the soil and rotten rock, the erosive power of the glacier mainly resulted in scouring and rounding off many of the hills; in cutting away considerable sandstone and

conglomerate from under the lava on the west and north side of the Mount Tom, Mount Holyoke, and Deerfield Ranges, thus steepening those mountain faces; and probably in removing some of the relatively weak Triassic strata from the valley floor, as, for example, in the Manhan River valley where the ice was crowded between the Mount Tom lava range and the hard granite mountains on the west side of the valley.

Glacial Deposits. The vast amount of *débris* transported by the great ice sheet was carried either on its surface, or frozen within it, or pushed along under it. It was exceedingly heterogeneous material ranging from the finest clay, through sand and gravel, to boulders of many tons weight. The deposition of these materials as we now see them took place during both the advance and retreat of the ice, but chiefly during its retreat. Most of the deposits made during the ice advance were obliterated by ice erosion, but those formed during the ice retreat have been left practically intact except for the small amount of Postglacial erosion.

A very extensive ice deposit called the "ground moraine" is simply the heterogeneous, typically unstratified, unconsolidated *débris* from the bottom, interior, and top of the ice which was deposited mostly during the retreat of the glacier. When it is mostly



FIG. 23. A GREAT PILE OF LOOSE GLACIAL MATERIAL KNOWN AS A "DRUMLIN," LEFT BY THE RETREATING GLACIER OF THE ICE AGE. THIS HILL IS ABOUT 150 FEET HIGH AND ONE-FOURTH OF A MILE LONG. PHOTOGRAPHED BY THE AUTHOR.

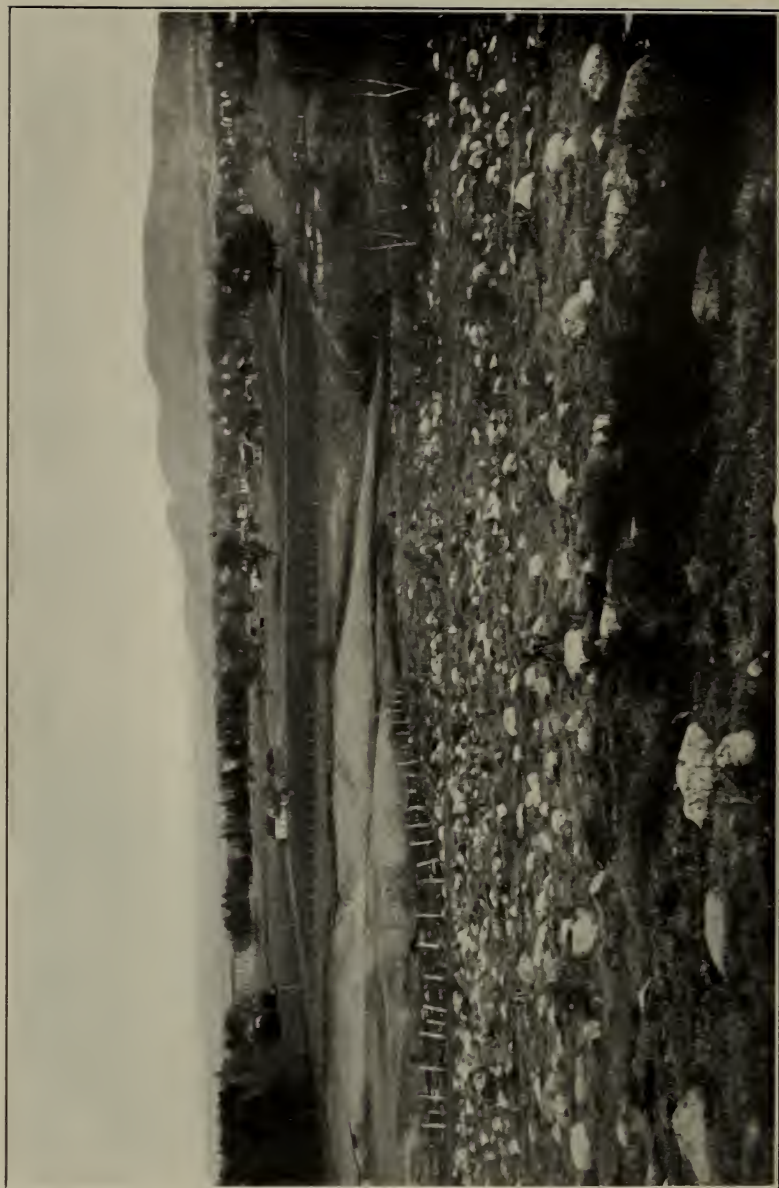


FIG. 24. A FIELD OF GLACIAL BOULDERS LEFT BY THE RETREATING GLACIER OF THE ICE AGE. STATE HOSPITAL GROUNDS IN NORTHAMPTON.
THE MOUNT HOLYOKE RANGE IN THE DISTANCE. PHOTOGRAPHED BY THE AUTHOR

very fine material with pebbles or boulders scattered through its mass, it is known as "boulder clay" or "till". The pebbles or boulders of the till are usually rounded or faceted and striated as a result of having been rubbed against the bed rock. Such ground moraine deposits are exceedingly widespread at the surface throughout central western Massachusetts except where they have been covered by Postglacial deposits or removed by Postglacial erosion. In fact such morainic materials constitute most of the soils of the region away from the valley floors.

An interesting type of glacial deposit is the "drumlin" which is, in reality, only a low, rounded hill of ground morainic material or till ranging in height up to 150 feet or a little more. Drumlins were formed either by rounding off or locally piling up of ground morainic material under the ice. There are many fine drumlins in the Connecticut Valley region. Perhaps the best district in which to observe them is the triangular area between Northampton, Williamsburg, and Whately where 20 or 30 may be seen. The finest one of all is a quarter of a mile long and 150 feet high north of Westbrook $1\frac{1}{2}$ miles northwest of North Hatfield station (see figure 23). Round Hill in Northampton is a drumlin. Among many other examples mention may be made of the hill on which Amherst College is built; Prospect Hill at Mount Holyoke College; three small hills just west of Holyoke; and McCarthy Hill just east of East Longmeadow.

Glacial boulders called "erratics" have already been referred to. They are simply blocks of rock from the top of the ice or within it which have been left strewn over the country as a result of the melting of the ice. They vary in size from small pebbles to many tons weight, and were naturally most commonly derived from the harder rock formations. Many of them have been transported long distances. Erratics are very numerous throughout most of New England. Locally they constitute veritable boulder fields where they are so large and numerous that farmers have not attempted to clear the land of them (see figure 24). By way of illustration of some of the geological history which these boulders represent, a group of three within a rod of each other at Mountain Park will be briefly described. They are shown in figure 25. The one in the middle is a very hard altered sandstone (or quartzite) from an early Paleozoic formation deposited under the sea at least 25 million years ago. It was torn from a ledge in southwestern Vermont and carried to its present position by the ice of the great Ice Age. On the left is a

boulder of granite representing once molten material which was forced into the earth's crust in late Paleozoic time at least 12 million years ago. It was carried by the ice from a ledge north or west of Northampton. The boulder on the left represents lava which flowed in molten condition upon the earth's surface in late Triassic time at least 8 million years ago. It was carried not more than a few miles by the ice. Veritably, these three erratics form a strange company.



FIG. 25. A STRANGE COMPANY OF THREE GLACIAL BOULDERS NEAR MOUNTAIN PARK. THE MIDDLE ONE WAS CARRIED BY THE GREAT GLACIER OF THE ICE AGE FROM SOUTHWESTERN VERMONT; THE ONE ON THE LEFT FROM THE VICINITY OF NORTHAMPTON; AND THE ONE ON THE RIGHT FROM THE MOUNT TOM RANGE. PHOTOGRAPHED BY THE AUTHOR.

Of special interest are the boulders commonly called "hard-heads" which are widely scattered over the region. They are like the first one of the group of three described just above. They are generally well rounded, exceedingly hard, and of a light gray to light brownish-yellow color. These very ancient (early Paleozoic) rocks were transported across northwestern Massachusetts from southwestern Vermont. Boulders of the late Paleozoic igneous rocks (mainly granite) are also very common and widespread not only because the ice plucked off many masses of these widely exposed rocks, but also because of their great hardness which prevented them from being ground to pieces by the action of the ice.

Very exceptionally, glacial boulders are left in remarkably balanced positions either just as they were deposited by the ice, or by Postglacial removal of loose materials from around them. A very fine example is the so-called "balanced rock" or "rocking stone" a little over 2 miles northwest of Westhampton village. It lies near the top of a high hill over 1400 feet above sea level. It is a granite boulder 9 feet long and 7 feet high resting by sharp contact on a ledge of Paleozoic altered stratified rock (Conway schist). Moderate pressure with the hand will cause this great boulder to sway back and forth very appreciably, and it continues to sway for a time after removal of the pressure. Figure 26 gives a good idea of this boulder.

Like ice erosion, so deposition of glacial materials has not changed the main topographic features of southern New England. The general tendency of ice deposits in the upland districts was to partially fill the depressions, and hence to diminish the roughness of the relief except locally. The relief of the broad floor of the Connecticut Valley was no doubt appreciably roughened by the irregular accumulation of glacial débris upon it.

Sinking of the Land During the Ice Age. Before leaving the discussion of the Ice Age, mention should be made of a change of level of the land. We have learned that, just before the Ice Age, the Connecticut Valley region of Massachusetts stood considerably higher above sea level than today. The notably greater altitude, causing a lower temperature of all of northeastern North America at that time, was no doubt one of the important factors in bringing on the Ice Age. Now, next to the most recent recorded movement of the land in the Connecticut Valley region was a subsidence, during a late stage of the Ice Age, to a level even lower than that of the present. That there has been a notable subsidence since early in the Ice Age is proved by the fact that the inner valleys or gorges, which were cut into the newly upraised broad valleys of the larger rivers such as the Hudson and Connecticut (see above discussion) just before the oncoming of the great glacier, are now well below sea level.

Postglacial Connecticut Valley Lake or Estuary. On the withdrawal of the vast ice sheet a great body of water covered most of the area of the Connecticut Valley proper. The water generally spread somewhat beyond the borders of the area of Triassic strata as shown on geologic map figure 10. Professor Emerson originally described this body of water as a lake, but more recently Professor Fairchild has argued that both this and a long narrow body of water

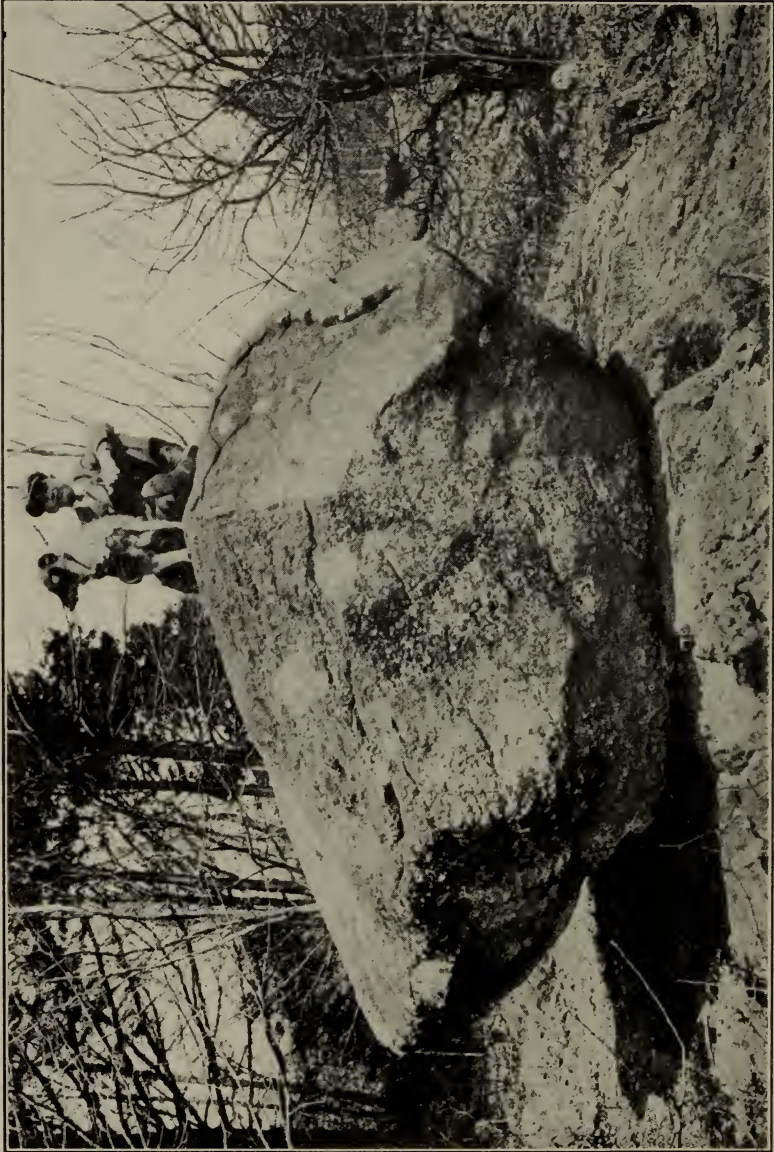


FIG. 26. THE "ROCKING STONE" ON THE HILL AT AN ALTITUDE OF 1400 FEET, TWO MILES NORTHWEST OF WESTHAMPTON VILLAGE. THIS GLACIAL BOULDER OF GRANITE, NINE BY SEVEN FEET, IS SO DELICATELY BALANCED THAT MODERATE PRESSURE WITH THE HAND WILL CAUSE IT TO SWAY BACK AND FORTH. PHOTOGRAPHED BY THE AUTHOR.

in the Hudson-Champlain Valley were Postglacial estuaries, and that the estuary of the Connecticut Valley had two very narrow connections with Long Island Sound. Although Fairchild is probably correct, nevertheless the great body of water which extended from near Middletown, Connecticut, through Massachusetts, and beyond as a very narrow northward extension far up the Connecticut Valley, was in all important respects a lake. Because of its very narrow connection with the sea, and the great volumes of water constantly feeding the lake, its water must have been fresh or at most only very slightly salty. We shall, therefore, refer to it as a lake.

In Massachusetts from Northampton northward the lake was 5 to 10 miles wide, and from Northampton southward it was 10 to 20 miles wide. It was almost completely cut in two by the Mount Tom-Holyoke Range and the long low lava ridge which extends southward from Mount Tom (see geologic map figure 10). These two parts of the lake in Massachusetts were connected only through the narrows of the Connecticut River at Mount Tom Junction; the narrows of the Westfield River between Westfield and Springfield; and through the deep valley at the very eastern end of the Holyoke Range. The Deerfield and Greenfield Ridges; the two Sugarloaf Mountains; and Mount Warner also projected as islands above the lake.

What is the nature of the evidence by which we know of the existence of this great Postglacial lake? The extensive deposits which accumulated in its waters constitute the best proof. Such deposits consist of sands, gravels, and clays. The stratified sands and gravels (especially the former) which so characteristically form wide flats or small plains were obviously deposited under standing water. Among the many very fine examples of such flats are the following: between Westfield and Southwick; north-northeast of Westfield (site of Camp Bartlett); east of Loudville; in the northern part of Florence; in the vicinities of Granby, Ludlow Center, and Ludlow City; south of the south spur of Mount Toby (west of Leverett); southwest of Miller's Falls; and between Bernardston and Northfield. These sand plains are generally best developed where the largest streams emptied into the lake because they are of the nature of delta deposits which filled into the lake up to its surface or nearly so. An excellent illustration of the delta character of these deposits may be observed where the Westbrook road makes the steep ascent over the delta front west of North Hatfield station. Excavation for road material has there laid bare a nearly vertical section

of the well stratified sands and gravels the layers of which show a decided slope eastward exactly as they were deposited by Westbrook where it emptied into the lake. From this place the delta terrace or flat extends west for one-half of a mile to the foot of the hill.

In support of the above view is the fact that there are extensive clay deposits well out in the Connecticut Valley. This is what would be expected if a large lake existed because the fine sediments (clays) would have been carried out into the midst of the deeper part of the lake, while the coarser materials (sands and gravels) would have accumulated in the shallower waters usually nearer shore. Now this is just what did happen in the Connecticut Valley lake. The sediments carried into the lake by Mill River at and near Northampton finely illustrate this principle. Where Mill River emptied into the lake half way between Florence and Leeds, a large deposit of coarse gravel was dumped as shown in the gravel pits by the electric railway. In the northern and western parts of Florence the broad delta plain of Mill River is perfectly exhibited, more gravelly towards the west, and more sandy towards the east (see figure 27). The western margin of this delta plain, free from glacial boulders, shows a sharp contact against the boulder strewn steep hillside, the base of the latter marking the shore of the lake. Between Florence and Northampton the deposit is more like loam, while under much of Northampton there is a great deposit of perfectly stratified clay in thin layers. This clay is well exposed in the brickyard clay pits in the city.

The very extensive perfectly stratified brick clays between Holyoke and Chicopee were also laid down in the deep quiet water in the midst of the lake. With shoaling of the water, sands were then extensively deposited on top of the clays as well shown in the brick yard clay pits. These clays and sands were washed in mainly by the Chicopee River.

That portion of the great lake which lay east of the lava rock ridge (see map) was not filled up as much in proportion as the part to the west of the ridge. One reason for this is that the Westfield River which fed the western part was much larger and swifter and hence carried a much greater load of generally coarser sediment than the smaller and slower Chicopee River which fed the eastern part. Another reason is that the eastern part of the lake was much larger and hence there was not time enough for it to fill up as much as the western part.



FIG. 27. PART OF THE WIDE SAND AND GRAVEL PLAIN JUST NORTHWEST OF FLORENCE. IT WAS FORMED AS A DELTA DEPOSIT, MAINLY BY MILL RIVER, IN THE GREAT POSTGLACIAL LAKE WHICH OCCUPIED THE CONNECTICUT VALLEY JUST AFTER THE ICE AGE. THE BASE OF THE BOULDER STREWN HILL IN THE DISTANCE MARKS THE SHORE LINE OF THE LAKE. PHOTOGRAPHED BY THE AUTHOR.

An interesting feature of the lake deposits, especially the higher level delta sand flats and plains, is the presence in many places of large holes or pits without outlets. These are known as "kettle-holes". They vary from a few rods to a half mile or more across, and in depth from a few feet to 50 or 75 feet. Most of them are dry, but some are more or less filled with water. They show a marked tendency to occur in groups. Two good ones lie within sight of the main road in the western part of Florence. Examples among many others are the following: on the sand flats between Florence and Loudville; in the vicinity of Indian Orchard; southwest of Miller's Falls; between Bernardston and West Northfield; and at the eastern end of the Holyoke Range. Hampton Pond between Holyoke and Westfield; most of the ponds around Indian Orchard and Ludlow; Upper, Middle, and Lower Ponds at the eastern end of the Holyoke Range; and Green Pond and Great Pond between Miller's Falls and Montague are all fine examples of kettle holes containing water. Each kettle-hole represents a place where a block of ice (iceberg) became stranded in the lake and was more or less buried under the sediments which were washed in by the streams. After a long time (on account of the coldness of the water) the ice melted and the sediments caved in leaving a hole or pit below the general level of the delta deposit.

It may be of interest to note that, in regard to accumulation of sediments in this Postglacial lake, there was a small scale tendency to repeat the conditions of accumulation of sediments on the floor of the great sinking Triassic basin millions of years before (see above). The coarse and fine sediments of both Triassic and Postglacial times deposited simultaneously, and in each case the general tendency was for the coarser materials (sands and gravels) to accumulate mostly relatively near the sides of the basin, while the finer materials (muds) were carried out farther into the midst of the basin.

We may be very certain that the lake existed after the disappearance of the glacier from the valley because no glacial deposits whatever rest upon the lake beds. This also explains the characteristic absence of glacial boulders from the delta terraces or plains. The Postglacial age of the lake is also proved by the fact that the lake deposits overlap the glacial deposits.

How long ago did the great lake exist in the Connecticut Valley? Various studies, mainly those based upon the origin and rate of retreat of Niagara Falls, have led us to the conclusion that the Ice Age ended at the latitude of western New York and Massachusetts not more than a few tens of thousands of years ago, hence the Connecticut Valley Postglacial lake could not have existed longer ago than that. But the length of time, as shown by the amount of erosion of the lake deposits, which has elapsed since the existence of the lake is at least some thousands of years. Professor Emerson, after discussing the character and origin of the clays, says: "Each layer thus represents a year's growth. As the clays are about 180 feet deep, and each layer about one-third of an inch thick, the lake may have remained about 6000 years".

The Most Recent Tilting of the Land. The delta deposits in the form of flats or plains which were built up to or near the surface of the great Postglacial lake in the Connecticut Valley do not lie at the same level across the state as they must have when they were formed. They show a steady and rather remarkably regular increase in altitude from south to north. The good examples of sand plains already mentioned as proofs of the former presence of the lake now show the following altitudes: between Westfield and Southwick, 270-280 feet; north-northeast of Westfield (site of Camp Bartlett), 280-290 feet; in the vicinities of Granby, Ludlow Center, and Ludlow City, 280-300 feet; east of Loudville and in Florence, 300-310 feet; south of the south spur of Mount Toby (west of Leverett), 320-330 feet; southwest of Miller's Falls, 350-370 feet; and more poorly

defined ones in the vicinities of Bernardston and Northfield, 370-390 feet. The whole region including Holyoke, Chicopee, Indian Orchard Springfield, and East Longmeadow shows no extensively developed high level lake deposits because, as explained above, this large portion of the lake was not so much filled with sediments. Lower level deposits which formed farther out are, however, extensively developed in that region.

From the above figures it is seen that the high level lake deposits are fully 100 feet higher in the northern part of the state than in the southern. Accepting Fairchild's view that the lake had tide water connection it is, then, evident that the land on the south side of the state has risen nearly 300 feet, while that on the north side has risen nearly 400 feet since the disappearance of the lake. Indeed this very southward tilting of the land has been the most important factor in causing the obliteration of the lake. This represents but a local part of the differential uplift of the land since the Ice Age over all of northeastern North America, probably due to the tendency of the earth's crust to slowly spring back toward its Preglacial level as a result of removal of the great weight of the vast sheet of ice.

To review the most recent crustal disturbances of the Connecticut Valley region, we have learned that just before the Ice Age the land stood notably higher than at present; that late in the Ice Age it sank several hundred feet below its present level; and that since the existence of the great Postglacial lake it has differentially risen several hundred feet to its present level.

Recent Erosion and River Shifting. Since the disappearance of the Postglacial lake, probably not more than 20,000 years ago, and the still later upwarp of the land, the Connecticut River has been engaged in cutting its way down into the loose Glacial and Postglacial deposits of the valley floor. The maximum depth to which the river has cut its way into these deposits appears to be somewhat more than 100 feet as, for example, north of Smiths Ferry, north of Holyoke, and between Holyoke and Chicopee. North of Chicopee the brick clay overlain with sand rises steeply as a well preserved bank against which the Connecticut River recently flowed. In but few places has the river cut down to bed rock. In such places it has done so only because it does not follow its Preglacial channel. As we have learned, the Preglacial channel is below sea level. Between Sunderland and Smiths Ferry the river nowhere flows on bed rock and its velocity is low, the river there being now less than 100 feet above sea level. Because of its low velocity, it has there for

many years been cutting down very little, but it has been shifting its channel back and forth east and west often for miles, while many large and small meanders or curves have developed. In other words, the river's work of lateral planation rather than down-cutting is now its dominant activity from Sunderland to Mount Tom Junction.

The greatest existing meander or curve is that from Hadley westward. The channel of the river was once through the eastern side of the village site when a curve to the west began to develop, and this has steadily worked its way westward to form the present meander several miles long. Some of the banks of its former channels are now plainly visible in Hadley.

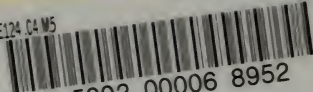
North of Hatfield village a recently abandoned channel (meander) of the river several miles long is very clearly shown with standing water or swamps throughout most of its length.

Most interesting of all of the recently abandoned channels of the Connecticut is, however, the so-called "oxbow" near Mount Tom Junction, because we know the year when that course was abandoned. Until the early part of 1841 the whole river followed the oxbow channel and then, at time of flood, it cut its way through the neck of the curve on the east to flow about where it is today.

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